WVT-QA-7201

FATIGUE BEHAVIOR OF THICK-WALLED CYLINDERS (7.62 MM RIFLED SPECIMENS)

TECHNICAL REPORT

JUNE 1972

QUALITY ASSURANCE DIRECTORATE

U.S. ARMY WEAPONS COMMAND
WATERVLIET ARSENAL
WATERVLIET – NEW YORK

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13. ABSTRACT

This report deals with fatigue life testing employing 7.62MM rifled barrels in order to secure information on the relationship of specimen life achieved through cyclic hydraulic pressure stressing and that achieved by firing of service type ammunition. Materials used included standard M14 rifle barrel stock from several suppliers and 175MM M113E1 cannon tube forging material from three suppliers.

The report also addresses the problem of "life" reliability prediction and demonstrates the potential usefulness of small barrel specimen testing in providing insight to "big gun" research, development, manufacturing, field support and quality engineering type problems.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fatigue Failure						
Pressure Cycling						
Fired Life						
Firing Damage						
Cannon Tube Material						
7.62MM Barrel Material						
Reliability Prediction/Verification						
Correlation Hydraulic Simulation/Firing						

1C

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BY

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AND

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(7.62 MM RIFLED SPECIMENS)

ABSTRACT

This report deals with fatigue life testing employing 7.62MM rifled barrels in order to secure information on the relationship of specimen life achieved through cyclic hydraulic pressure stressing and that achieved by firing of service type ammunition. Materials used included standard M14 rifle barrel stock from several suppliers and 175MM M113A1 cannon tube forging material from three suppliers.

The report also addresses the problem of "life" reliability prediction and demonstrates the potential usefulness of small barrel specimen testing in providing insight to "big gun" research, development, manufacturing, field support and quality engineering type problems.

CROSS REFERENCE DATA

Fatigue Failure

Pressure Cycling

Fired Life

Firing Damage

Cannon Tube Material

7.62MM Barrel Material

Reliability Prediction/
Verification

Correlation Hydraulic
Simulation/Firing

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1. INTRODUCTION

Establishment of safe cannon life by the firing of ammunition is expensive, particularly when determining risk levels associated with metal fatigue of a critical component such as a cannon tube. Firing a single 155MM howitzer tube to its fatigue life for a price of one million dollars is considered a bargain. Destruction of a sufficient number of tubes by firing to achieve a statistically valid reliability quickly becomes prohibitive even with full consideration to moral issues and professional ethics. Duplication of firing phenomenon with attendant extremes in temperatures, pressure, and energy being developed in minimal time is difficult if not impossible. Therefore in order to gain a better understanding of life testing, small size specimen experimentation appeared as a logical approach for generation of data by which to look into the theoretical, statistical and experimental methods now being explored by many investigators.

2. OBJECTIVES

The immediate goals of this study are:

a. To correlate ammunition firing pressure fatigue effects to hydraulic pressure cycling fatigue effects using thick walled gun barrels.

b. To determine fatigue life performance of cannon tube material furnished by different contractors, produced to a common specification but by proprietary processes.

The long range goal of this study and similar future studies is to develop a more sensitive material test that would permit categorization of tube forgings by life expectancy.

3. APPROACH

Phase I - "Establishment of Test Techniques" -

The 7.62MM Rifle M14 was selected as a test vehicle because of low cost and availability of ammunition and rifle barrels. Since the fatigue life of a standard M14 rifle barrel was estimated high in comparison with that of a typical cannon, it was decided to neck down the barrel just over the origin of rifling to about four to six inches down barrel in order to precipitate earlier failure. Initial tests were run with barrels necked to a 1.4 wall ratio (ratio of outside diameter to inside rifling groove diameter). A rate of fire of six (6) rounds per minute was selected as being reasonable. Even at this low rate, barrel heating seriously degraded life (barrels turned blue) and a decision was made to water cool the remaining 1.4, 1.6, and 1.8 wall ratio specimens during firing. (See Appendix A for information and data pertaining to this phase of work).

Phase II - "Correlation of Hydraulic Pressure Cycled Life to Fired Life" -

The following decisions were made based on Phase I results:

a. Use a standard proof fired M14 barrel modified to a 1.8 wall ratio in the vicinity of the origin of rifling.

b. Fire at 6 rounds per minute.

c. Water cool the critical barrel area to minimize temperature effects on barrel material.

d. Use standard M14 rifle ammunition. Lot [illegible].

e. Hydraulic cycle at 44,000 PSI at 7 cycles per minute.

A sketch of the M14 rifle barrel modification, photographs of the firing stand and hydraulic pressure cycling equipment are shown in Appendix B. In order to demonstrate the relationship between firing and hydraulic pressure cycling, five levels of testing were selected with three replicates at each level. The levels were set by amounts of firing (beyond initial proof) to be performed on each specimen i.e., 0, 1000, 2,000, 3,000, and 4,000 rounds. All specimens were subsequently hydraulically pressure cycled to destruction. In order to confirm fatigue life predicted by the above mentioned testing, three additional barrels were fired to destruction.

<u>Phase III</u> – <u>"Comparison of 175MM Tube Forging Material</u>

<u>Produced by Three Contractors X, Y, Z"</u>

Nine 175MM tube forging breech end sections (three from each of three suppliers) were trepanned to secure longitudinal 1.5" diameter bars for manufacture of 7.62MM size fatigue specimens.

This test series consisted of 9 specimens to be destroyed by pu. hydraulic pressure cycling (no firing); 9 specimens fired to destruction (no hydraulic cycling), and 15 specimens fired to specified levels followed by hydraulic cycling to destruction.

Additional specimens were also planned to cover unexpected events.

[illegible], rate of fire, rate of hydraulic cycling, specimen geometry, ammunition type etc., were the same or very similar to those used in Phase II. See Appendix I for method of specimen selection, and the Phase III test plan.

4. [illegible]

Phase I – "Establishment of Test Technique"

The information shown in Appendix A shows the feasibility of using the M14 rifle and ammunition system for [illegible] rifled, thick walled barrel fatigue behavior.

The heat check crack formation, the crack growth, and final rupture is considered similar to those normally experienced in cannon barrels.

Phase II – "Correlation of Hydraulic Pressure Cycled Life to Fired Life"

[illegible] of the data generated from tests at the following test levels

TEST LEVEL	[illegible]	[illegible] CYCLES	[illegible] PER TEST LEVEL
1	[illegible] [illegible] [illegible]	12,[illegible] 15,[illegible] 8,[illegible]	12,[illegible]
2	1,[illegible] 1,[illegible] 1,[illegible]	8,[illegible]9 [illegible] 11,[illegible]	9,47[illegible]

TEST LEVEL	ROUNDS FIRED	HYDRAULIC CYCLES	AVG HYD CYCLES PER TEST LEVEL
	2,000	10,462	
3	2,000	7,416	7,808
	2,000	5,546	
	3,000	2,973	
4	3,000	7,046	6,373
	3,000	9,101	
	4,000	2,939	
5	4,000	2,474	2,666
	4,000	2,587	
	5,683	0	
6	6,263	0 Avg	6,144
	6,487	0 Rds	

are shown in Appendix C and yields a relationship between hydraulic pressure cycled specimen life to fired specimen life of

$$Y_{(cycles)} = - 2.21\ X_{(rounds)} + 12,122$$

or 2.21 hydraulic cycles are equal to one fired round.

It should be noted that although large differences are evident among individual specimen lives at any one level, the average life at each level closely adheres to the straight line relationship.

The fired to destruction barrels (test level 6) confirm the validity of the resultant equations power in predicting mean fatigue or catastrophic failure.

An analysis of variance was performed on the six (6) levels, three (3) replicates per level and there appears to be no significant difference among the mean equivalent lives at each

level. See Appendix D for details.

A reliability life determination is shown in Appendix E along with photographs of failed M14 rifle specimens.

An application of the life prediction technique, used with the M14, to standard cannon is shown in Appendix F. The concept of retiring 1000 or more safe still usable tubes to prevent a single accident as a result of metal fatigue has in recent years become an acceptable practice. Additional safeguards are also provided as a result of other reasons for condemnation such as bore wear (origin or muzzle), rifling damage, rust or pitting, transportation hazards, enemy action etc.

Phase III - "Comparison of 175MM Tube Forging Material Produced by Three Contractors X, Y, Z."

Data generated from this experiment and a graphical portrayal of this data is shown in Appendix H.

Comparing M14 rifle material plot to 175MM gun material plot shows more variation in M14 rifle material life. This may be attributed to the fact that all 175MM specimens were manufactured by one machinist on common m chinery while the M14 rifle barrels were drawn from stock and involve a variety of manufactures.

In both the M14 test and the 175MM material test, hydraulic pressure cycling was performed at about 3000 PSI less than the average firing pressure. This might account for the M14 2:1 hydraulic cycles per firing cycle but then it does not account for the 1:1 relationship shown with 175MM material with specimen fired beyond the 500

round level. See Appendix N for ammunition calibration information.

The 175MM material appears to be very seriously affected by firing damage as demonstrated on the graph with the pure (unfired) hydraulically pressure cycled specimens versus those fired to destruction. Also the combination fired/cycled 5 rd., 50 rd., and 100 rd. specimens show a sizable drop in life as compared with the unfired specimens. The M14 material did not exhibit this effect although proof of one round may promote sufficient firing damage to account for this condition.

In order to perform a comparison of life data within a forging, among forgings from a particular supplier, and among forgings from different suppliers, data was transformed to a common base as shown in Appendix I. The difference among forging life data are considered normal and acceptable fatigue behavior irrespective of forging supplier. Material properties and quality are considered to be effectively the same. Appendix J contains life/reliability information. Appendix K shows life and material properties data and plots while Appendix L contains photos of specimens fired to destruction.

Appendix M shows information on a field failure and specimen test results. While the results cover a wide range, from 1676 rounds through 7810 rounds, the three out of four low life values indicate cause for concern about material behavior.

5. CONCLUSION

The multi-level testing technique and 7.62MM bore fatigue specimens, as demonstrated by these studies, are each considered useful tools and reasonable (cost/effective) methods for problem exploration.

Typical problems for possible application being:

- Swage tube vs hydraulic autofrettage tube life
- Rate of fire effects
- Effects of pressure levels
- Changes in chemistry
- Changes in heat treat
- Changes in forging practices
- Chrome or other type plating effects
- Refractory liners
- Cooling effects
- Aging and rest between firing effects
- Hydrogen embrittlement
- Long term storage chemical effects
- Straightening
- Thermal treatment effects
- Dirt size and count

6. RECOMMENDATION

Continued funding of projects using specimens of the type employed in this study in order to promote knowledge for production of superior cannon tubes and safely exploiting maximum life from these tubes.

A

APPENDIX A

(PHASE I)

ESTABLISHMENT OF TEST TECHNIQUES

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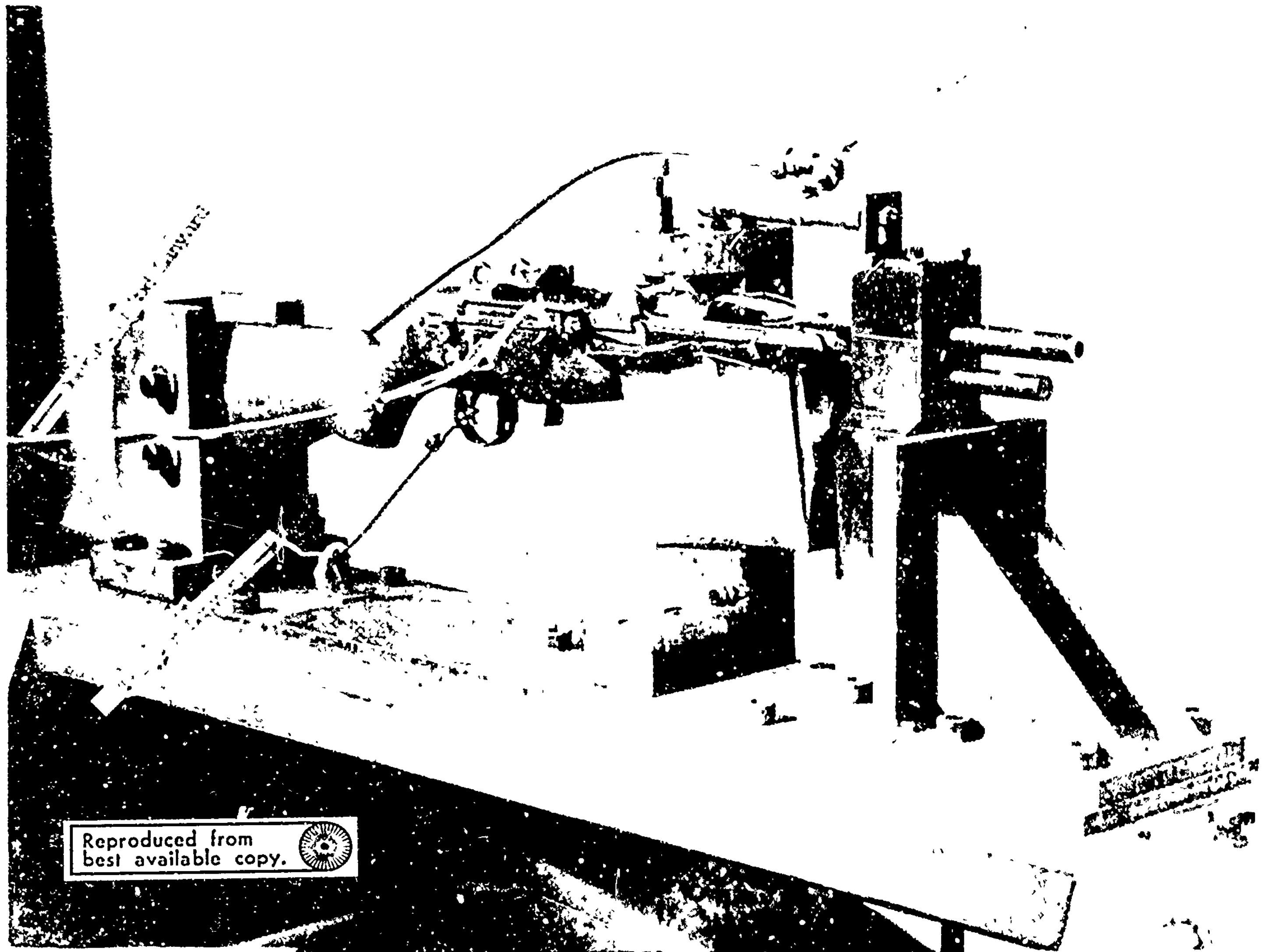
A

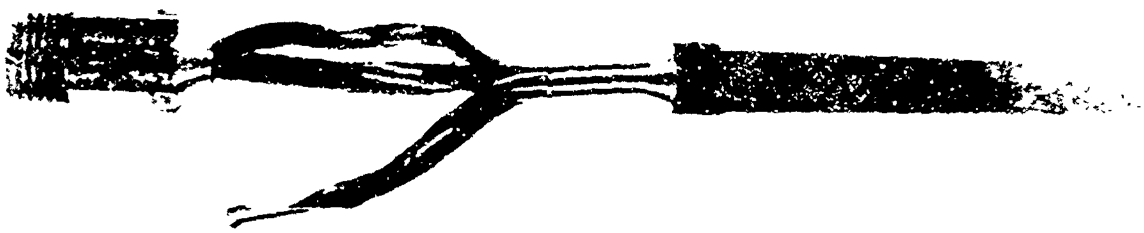


Firing Fixture (7.62MM) w/Water Cooled System & Firing Lanyard

A

7.62MM Modified M14 Rifle Barrels
1.4 Wall Ratio Fatigue Specimens
Air Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 10½", Ammunition Lot LC 13023
Project No. 4332-1, Negative No. 197-4-69

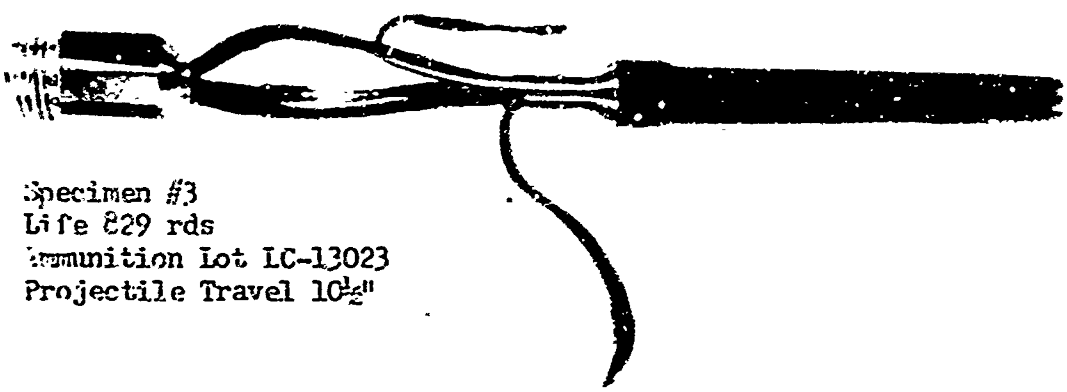
Specimen #1
Life 387 rds



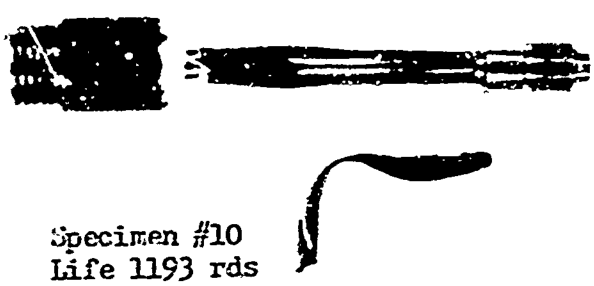
Specimen #2
Life 69 rds

A

7.62MM Modified M14 Rifle Barrels
1.4 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Project No. 4332-1, Negative No. 197-2-69



Specimen #3
Life 829 rds
Ammunition Lot LC-13023
Projectile Travel 10½"

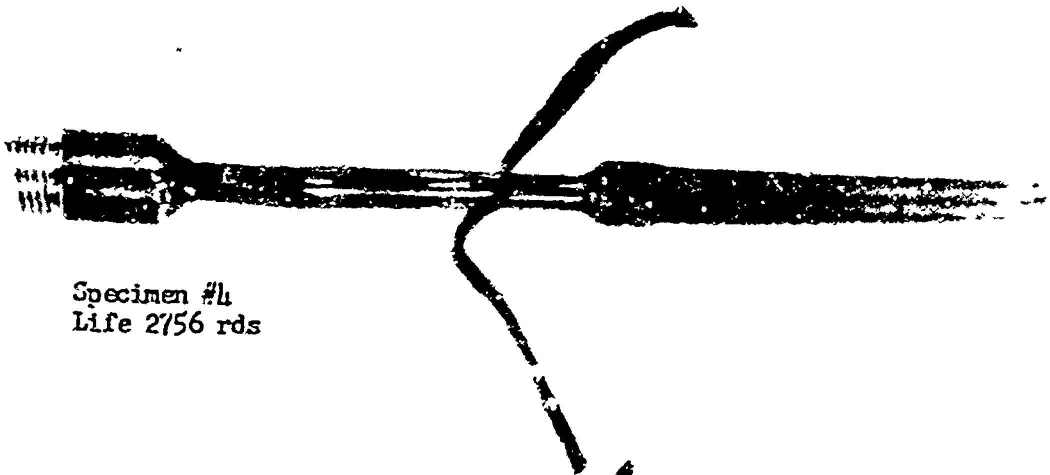


Specimen #10
Life 1193 rds
Ammunition Lot WRA-22713
Projectile Travel 19¼"

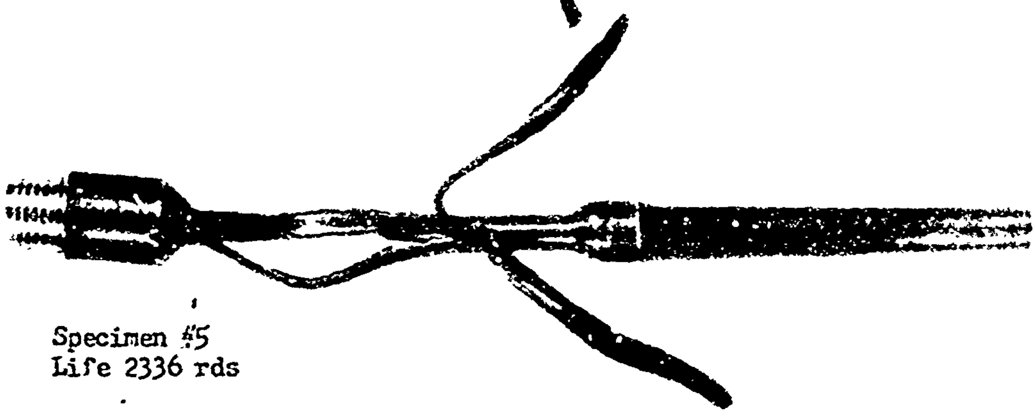
Specimen #11
Life-1044 rds
Ammunition Lot WRA-22713
Projectile Travel 19¼"

A

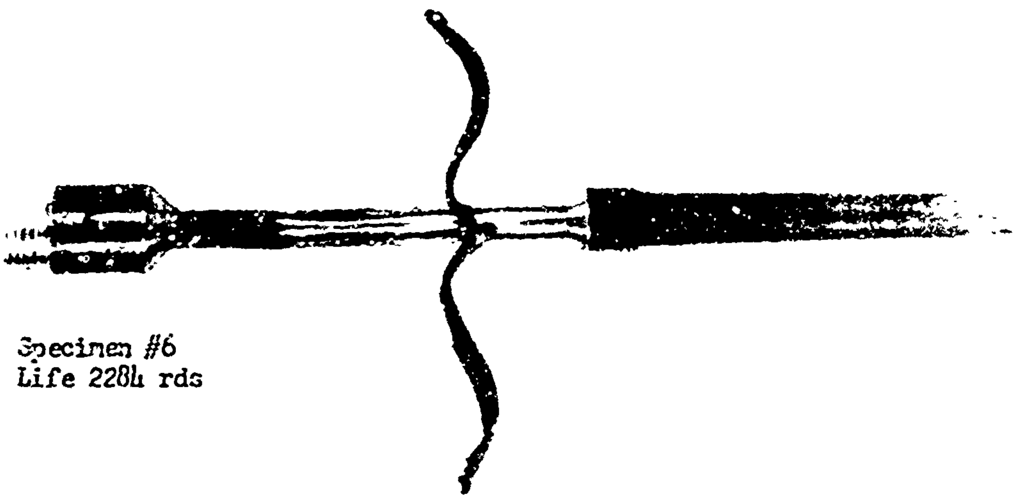
7.62MM Modified M14 Rifle Barrels
1.6 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 10½", Ammunition Lot LC 13023
Project No. 4332-1, Negative No. 197-1-69



Specimen #4
Life 2756 rds



Specimen #5
Life 2336 rds

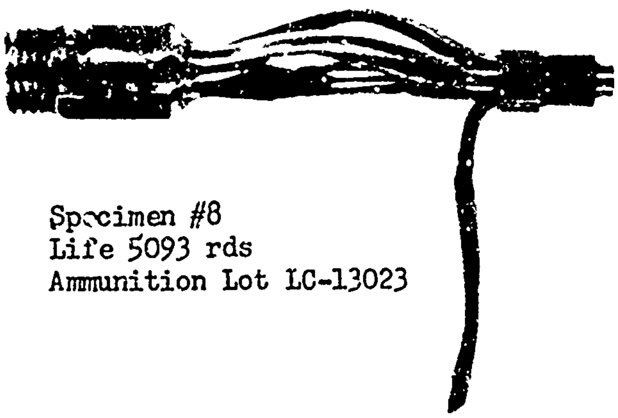


Specimen #6
Life 2284 rds

A

7.62MM Modified M14 Rifle Barrels
1.8 Wall Ratio Fatigue Specimens
Water Cooled, Rate of Fire 6 Rds/Min
Projectile Travel 19¼", Project No. 4332-1
Negative No. 197-3-69

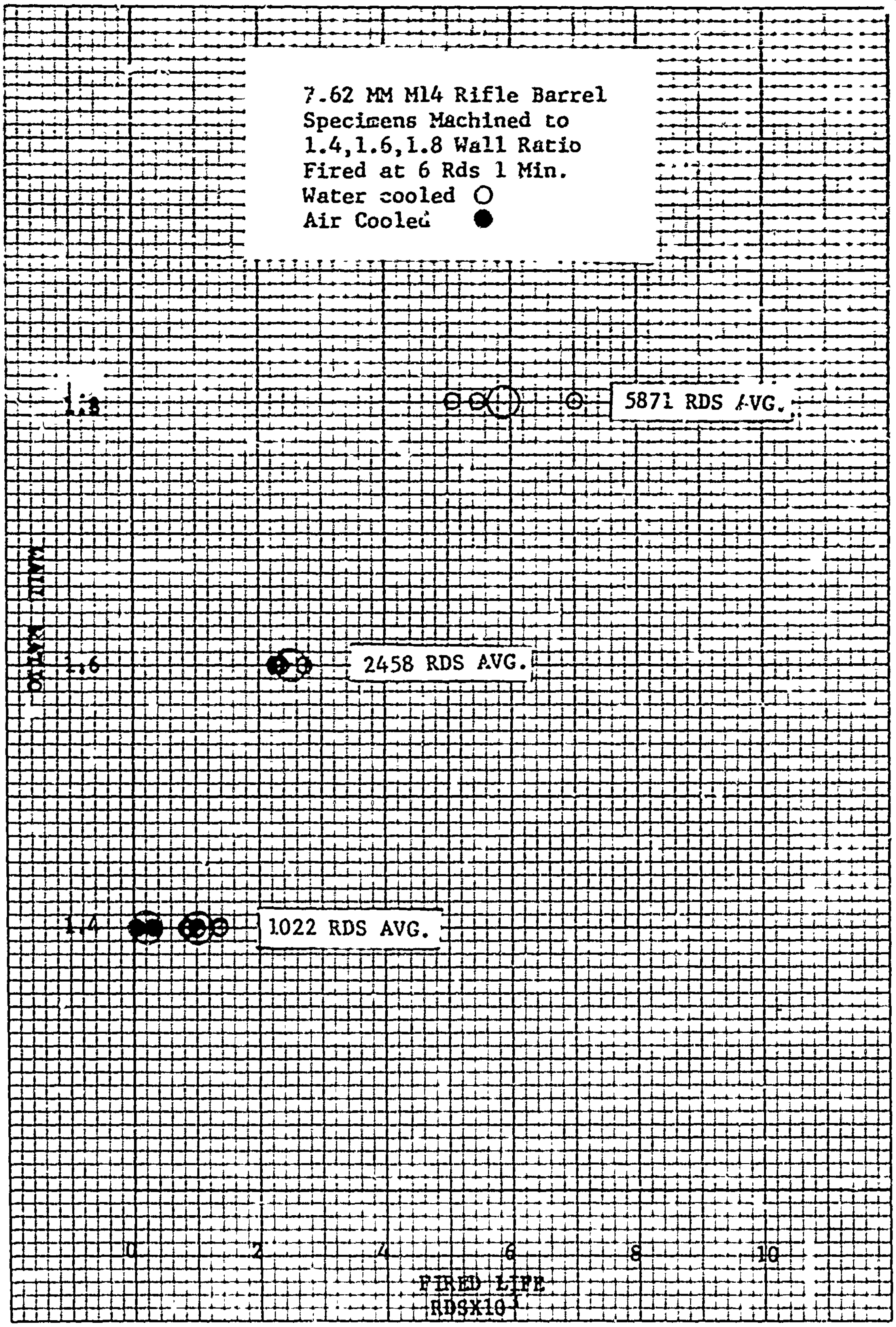
Specimen #7
Life 5474 rds
Ammunition Lot LC-13023



Specimen #8
Life 5093 rds
Ammunition Lot LC-13023

Specimen #9
Life 7047 rds
Ammunition Lot WRA-22713

A



7.62 MM M14 Rifle Barrel
Specimens Machined to
1.4,1.6,1.8 Wall Ratio
Fired at 6 Rds 1 Min.
Water cooled
Air Cooled
5871 RDS AVG.
2458 RDS AVG.
1022 RDS AVG.
1.6
1.4
0
2
4
6
8
10
FIRED LIFE

A

Specimen #5 Heat Check Pattern

[illegible]

A-7

B

APPENDIX B

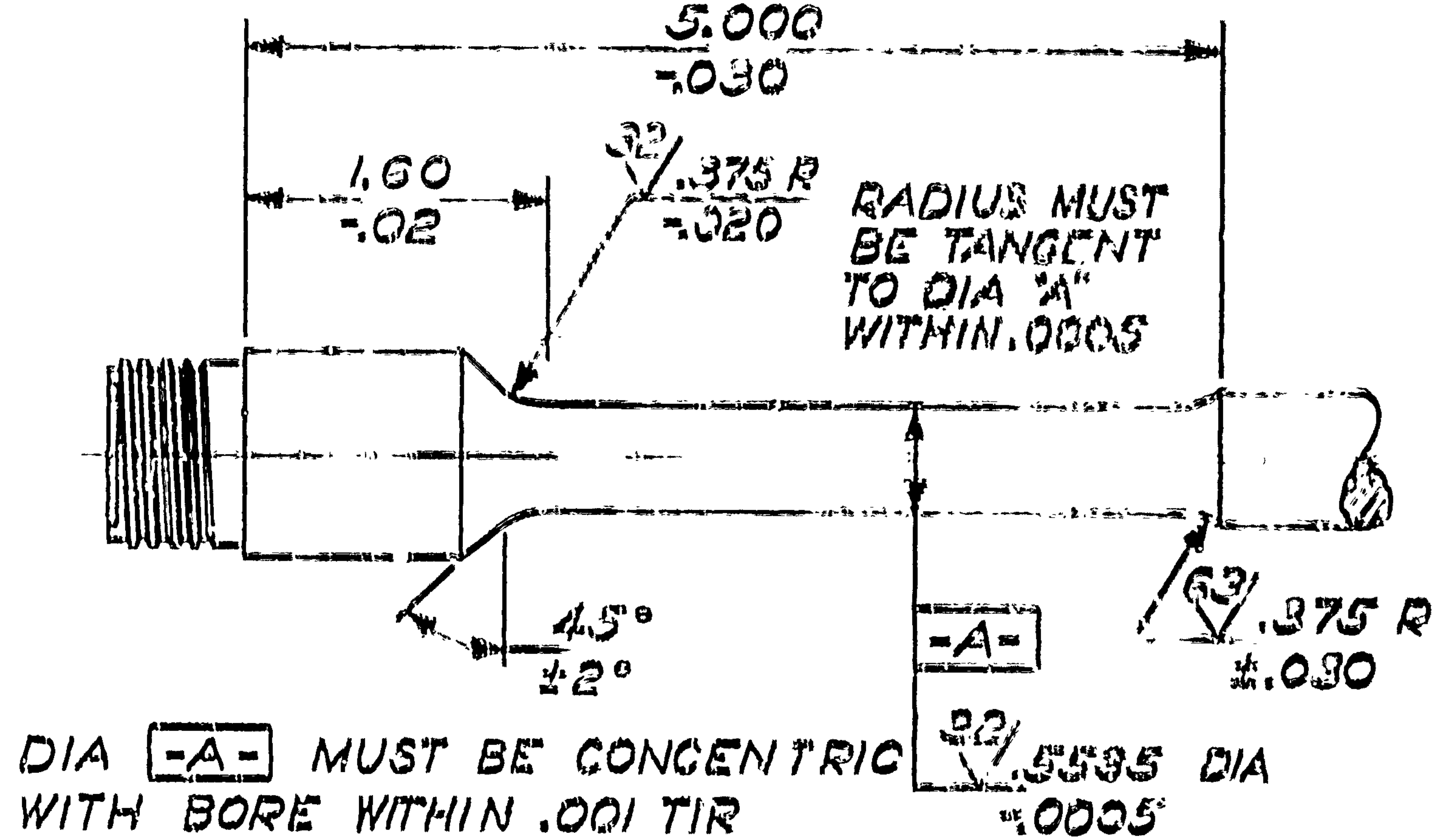
(PHASE III)

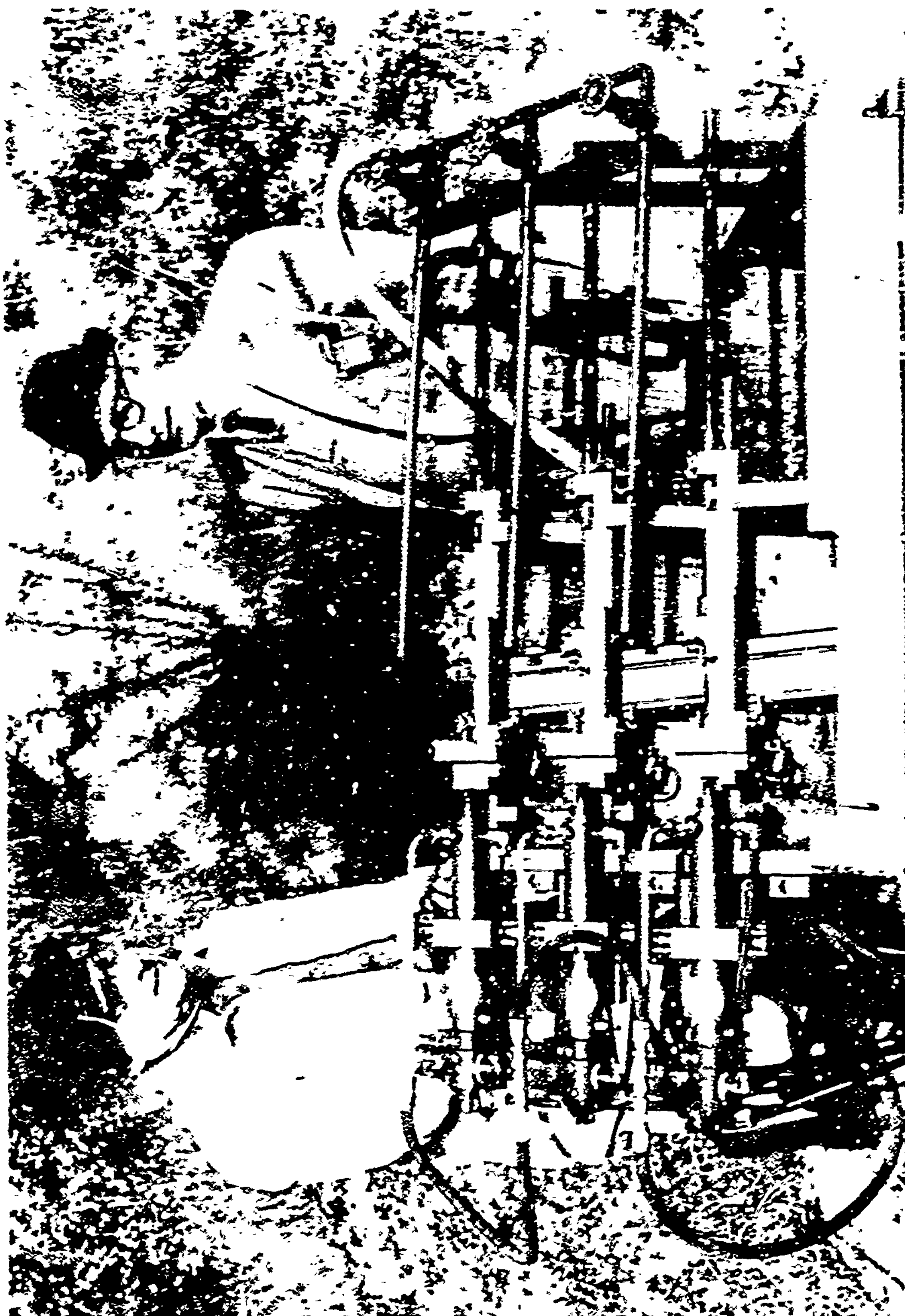
[illegible]

NO.		PAGE
1.	Modification Sketch for 7.62MM M14 Test Specimen	18
2.	Triple Gun Firing Test Stand	19
3.	Hydraulic Pressure Test Stand	20

MODIFICATION OF BARREL, RIFLE; 7.62 MM, M14

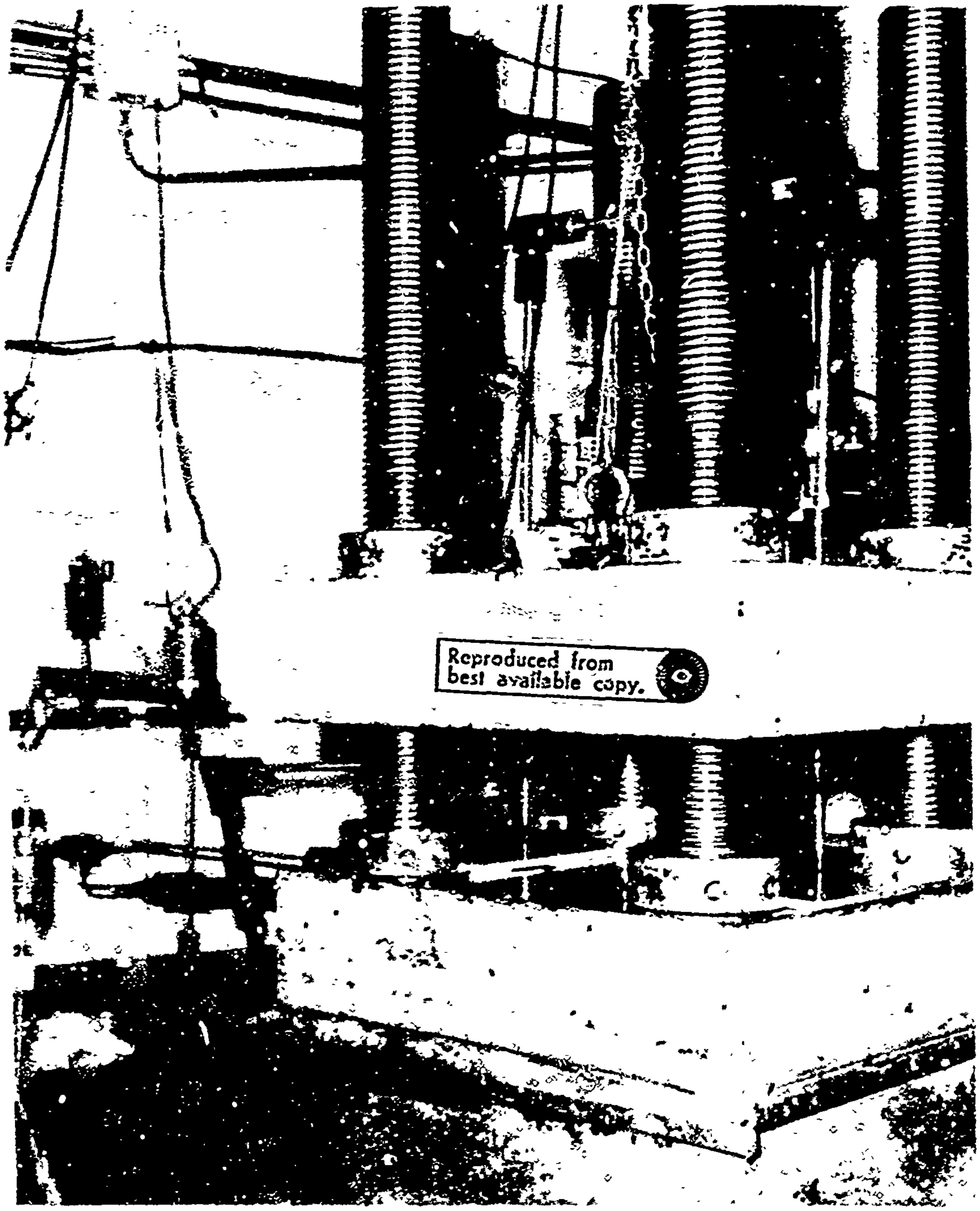
FSN 1005-628-9052 — DWG 7790190





Triple Gun Firing Test Stand

B



Hydraulic Pressure Test Stand

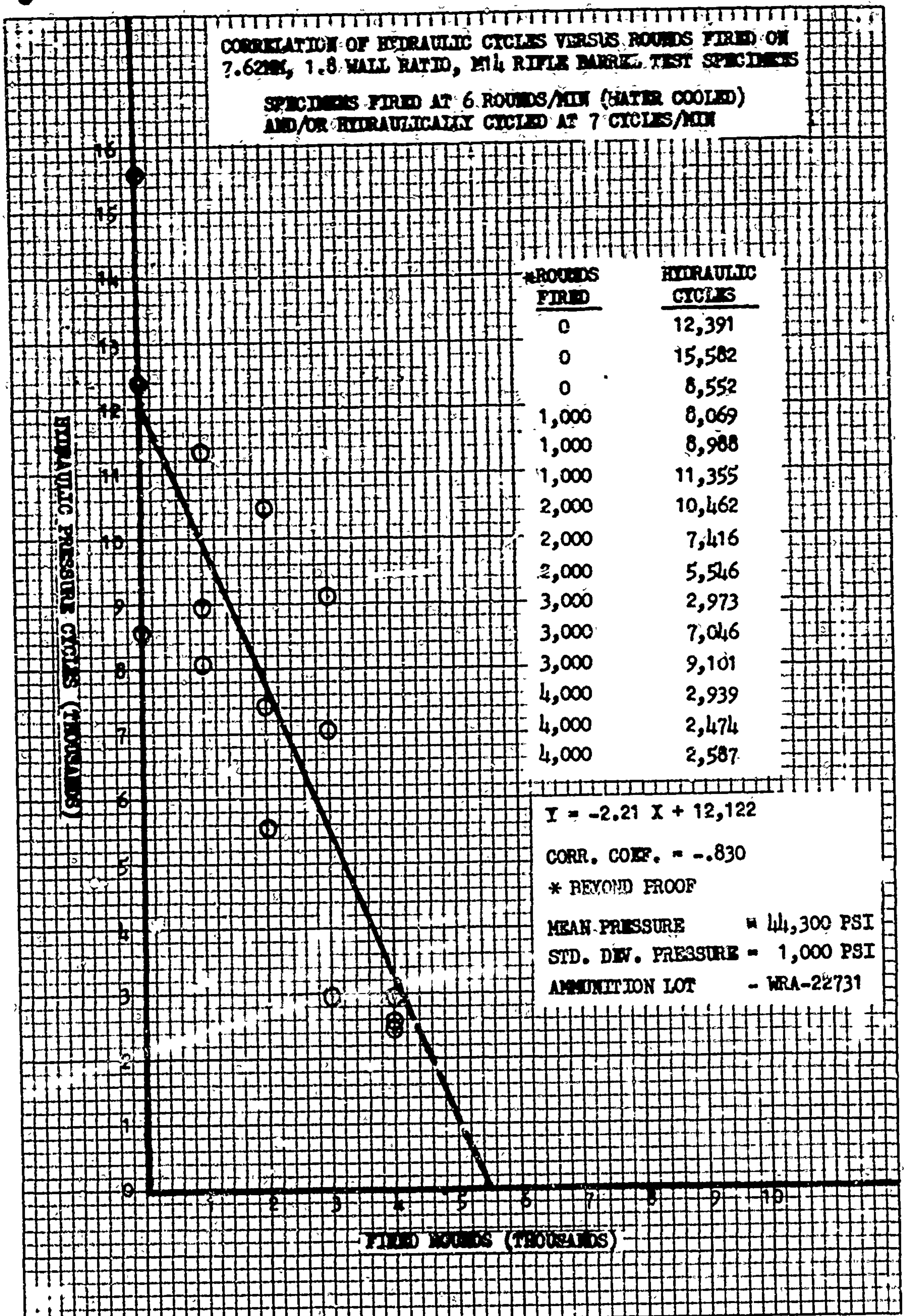
APPENDIX C

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

NO.		PAGE
1.	Graph - Hydraulic Cycles vs Rounds Fired	22
2.	Graph - Avg Hydraulic Cycles vs Rounds Fired	23

C


CORRELATION OF HYDRAULIC CYCLES VERSUS ROUNDS FIRED ON 7.62MM, 1.8 WALL RATIO, M14 RIFLE BARREL TEST SPECIMENS
SPECIMENS FIRED AT 6 ROUNDS/MIN (WATER COOLED) AND/OR HYDRAULICALLY CYCLED AT 7 CYCLES/MIN
*ROUNDS FIRED | HYDRAULIC CYCLES
0 | 12,391
0 | 15,582
0 | 8,552
1,000 | 8,069
1,000 | 8,988
1,000 | 11,355
2,000 | 10,462
2,000 | 7,416
2,000 | 5,546
3,000 | 2,973
3,000 | 7,046
3,000 | 9,101
4,000 | 2,939
4,000 | 2,474
4,000 | 2,587
Y = -2.21 X + 12,122
CORR. COEF. = -.830
* BEYOND PROOF
MEAN PRESSURE = 44,300 PSI
STD. DEV. PRESSURE = 1,000 PSI
AMMUNITION LOT - WRA-22731
HYDRAULIC PRESSURE CYCLES (THOUSANDS)
FIRED ROUNDS (THOUSANDS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

C

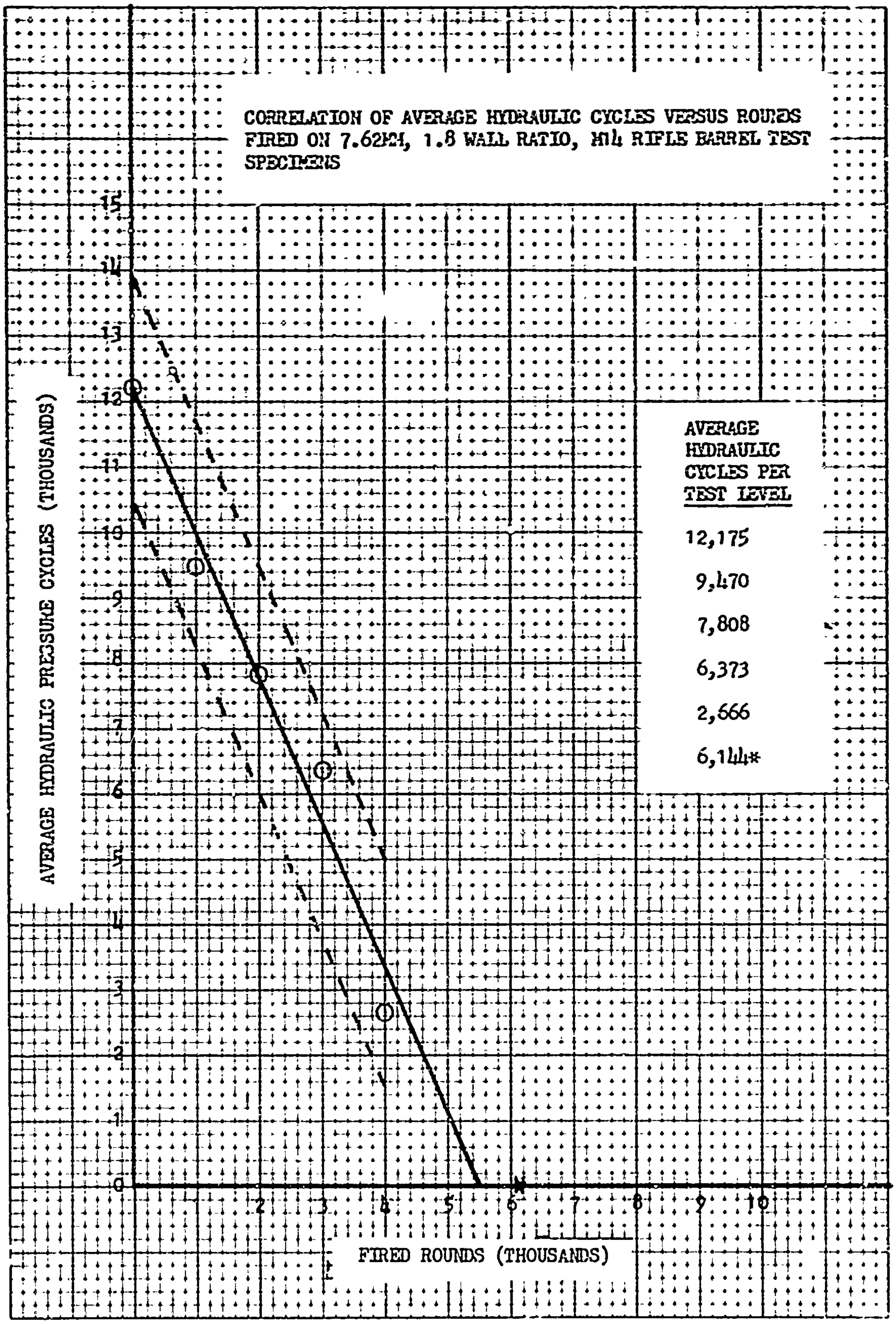
APPENDIX C

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

NO.		PAGE
1.	Graph - Hydraulic Cycles vs Rounds Fired	22
2.	Graph - Avg Hydraulic Cycles vs Rounds Fired	23

C


CORRELATION OF AVERAGE HYDRAULIC CYCLES VERSUS ROUNDS FIRED ON 7.62MM, 1.8 WALL RATIO, M14 RIFLE BARREL TEST SPECIMENS
AVERAGE HYDRAULIC PRESSURE CYCLES (THOUSANDS)
FIRED ROUNDS (THOUSANDS)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
AVERAGE HYDRAULIC CYCLES PER TEST LEVEL
12,175
9,470
7,808
6,373
2,666
6,144*

D

APPENDIX D

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

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2.	Graphs - Average Equivalent Rounds vs Test Level and Frequency vs Equivalent Rounds	26
3.	Analysis of Variance	27-30

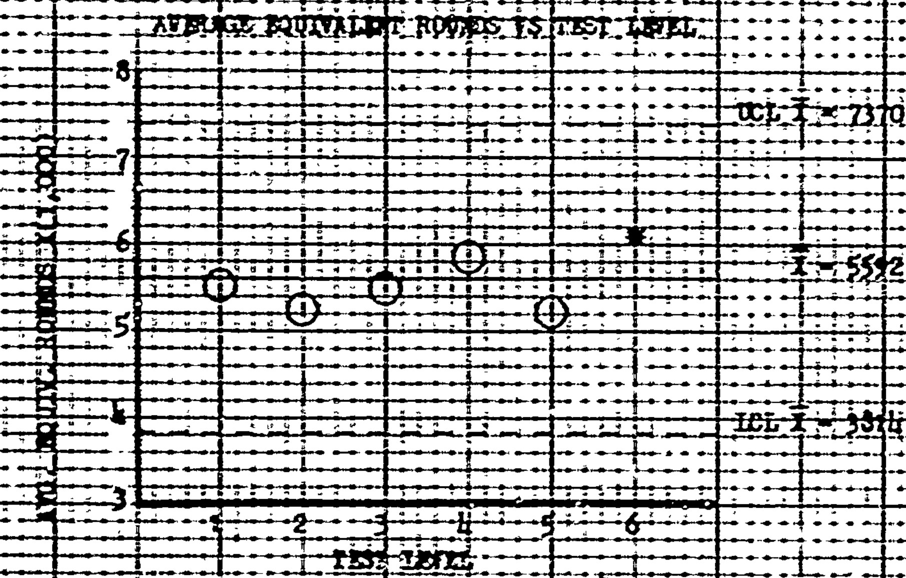
D

CONVERSION TO EQUIVALENT ROUNDS

$$I(\text{Rounds}) = \frac{I(\text{Cycles})}{2.211}$$

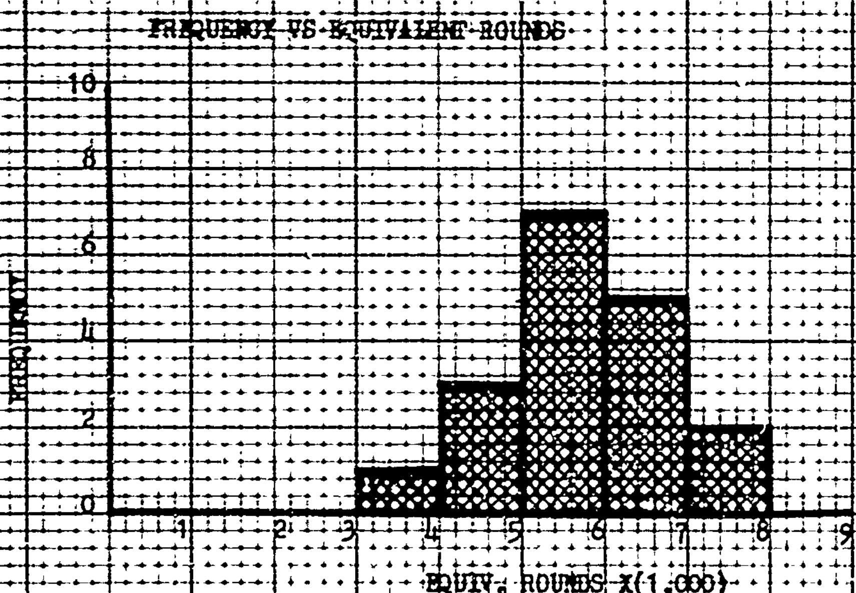
1	2	3	4	5	6
TEST LEVEL	FIRING CYCLES	HYDRAULIC CYCLES	AVG HYD CYCLES PER TEST LEVEL	RDS/ EQUIV RDS TO FAILURE	AVG RDS/ AVG EQUIV RDS TO FAILURE
	0	12,391		5,603	
1	0	15,582	12,175	7,046	5,506
	0	8,552		3,867	
	1,000	8,069		4,649	
2	1,000	8,988	9,470	5,064	5,283
	1,000	11,355		6,135	
	2,000	10,462		6,731	
3	2,000	7,416	7,808	5,354	5,531
	2,000	5,546		4,508	
	3,000	2,973		4,344	
4	3,000	7,046	6,373	6,186	5,882
	3,000	9,101		7,115	
	4,000	2,939		5,329	
5	4,000	2,474	2,666	5,119	5,206
	4,000	2,587		5,170	
	5,683	0		5,683	
6	6,263	0	6,144	6,263	6,144
	6,487	0		6,487	

D



TEST LEVEL	1	2	3	4	5	6*
EQUIV RDS	5,603	4,649	6,731	4,344	5,329	5,683
TO	7,046	5,064	5,354	6,186	5,119	6,263
FAILURE	3,867	6,135	4,508	7,115	5,170	6,487
AVERAGE	5,506	5,283	5,531	5,882	5,206	6,144

*ALL FIRED



D

ANALYSIS OF VARIANCE (ANOVA)

In general, there are three ANOVA classifications:

(i) FIXED EFFECTS - Where particular levels of a factor are studied and the result is a comparison of mean effects of THOSE particular levels.

(ii) RANDOM EFFECTS - Where levels of each factor are randomly chosen from a large finite or infinite population of levels and the resulting analysis estimates the component of variance contributed by each factor to the total variance rather than the main effects and interactions at particular levels of each factor.

(iii) MIXED

The combination of (i) and (ii) resulting in a more complicated analyses.

The analysis of variance technique enables us to partition the variance of the measured variable into portions caused by the factors, singly or in combination, and an experimental error component.

ONE FACTOR ANALYSIS

PURPOSE ...

To compare "L" different levels of a single factor having "M" replicates (repeat experiments) per level.

ASSUMPTIONS ...

(i) The "M" replications for any level represent a sample drawn at random from a normal population.

D

(ii) (a) FIXED EFFECTS

The "L" levels are systematically chosen as the important (or only) levels of the factor.

(b) RANDOM EFFECTS

The "L" levels are randomly chosen from a normal population of levels of the factor.

ANALYSIS ...

Let ...

$\alpha \equiv$ Level of Significance

$L \equiv$ Number of Levels

$M \equiv$ Number of Replicates

$N \equiv (L)(M) \equiv$ Sample Size

$X_{it} \equiv$ Replication t of Level i

Then, the partitioning of the total sum of squares (S.S.) of deviations from the mean into its components is as follows:

Source of Variation:

Among Levels

$$\text{S.S.(AMONG)} = \frac{L \sum_{i=1}^{L} \left(\sum_{t=1}^{M} X_{it} \right)^2 - \left(\sum X_{it} \right)^2}{N}$$

... associated degrees of freedom = (L-1)

Within Levels

S.S.(WITHIN) = S.S.(TOTAL) - S.S.(AMONG)

... associated degrees of freedom =(N-L)

Total Sum of Squares:

$$\text{S.S.(TOTAL)} = \frac{N \sum_{i,t} X_{it}^2 - \left(\sum_{i,t} X_{it} \right)^2}{N}$$

... associated degrees of freedom = (N-1)

D

The Mean Squares (variance estimates) are formed by dividing the Sum of Squares by their associated degrees of freedom.

If the null hypothesis (H_0) of no difference among levels (equal means) is true, then the mean squares (M.S.), among and within, are independent estimates of the same quantity and should be approximately equal (except for sampling error) with a ratio (among M.S. to within M.S.) near unity. A ratio greater than or equal to the tabled value for (L-1, N-L) degrees of freedom would occur in random sampling with probability α if H_0 were true. Therefore, we would reject the null hypothesis and say there is a difference among levels (i.e., averages).

If an F - ratio less than unity is calculated, consideration should be given to its reciprocal being statistically significant rather than accepting H_0 immediately. If the reciprocal is significant, possibly the postulated model is inadequate (Reference 2).

ANOVA, FIXED EFFECTS, LEVELS 6, REPLICATES 3

LEVEL	1	2	3	4	5	6
EQUIVALENT	5603	4649	6731	4344	5329	5683
ROUND	7046	5064	5354	6186	5119	6263
REPLICATES	3867	6135	4508	7115	5170	6487

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE
Among	1,934,449	5	386,890
Within	13,106,290	12	1,092,190
Total	15,040,740	17	

D

Resulting F ratio is .354 which is less than the table value 3.11 and therefore there is no significant difference among the mean lives of the six (6) levels considered.

Similarly the reciprocal of the F ratio, 1/F is 2.82, which is less than the table value of 4.68, and the model can be considered adequate. (Reference 3, tables).

References:

1. STATISTICS MANUAL by E. Crow, F. Davis, M. Maxfield, Dover Publications
2. STATISTICS IN RESEARCH by B. Ostle, Iowa State University Press
3. ENGINEERING STATISTICS by A. H. Bowker and G. J. Lieberman

E

APPENDIX E

(PHASE II)

CORRELATION OF HYDRAULIC PRESSURE CYCLED LIFE TO FIRED LIFE

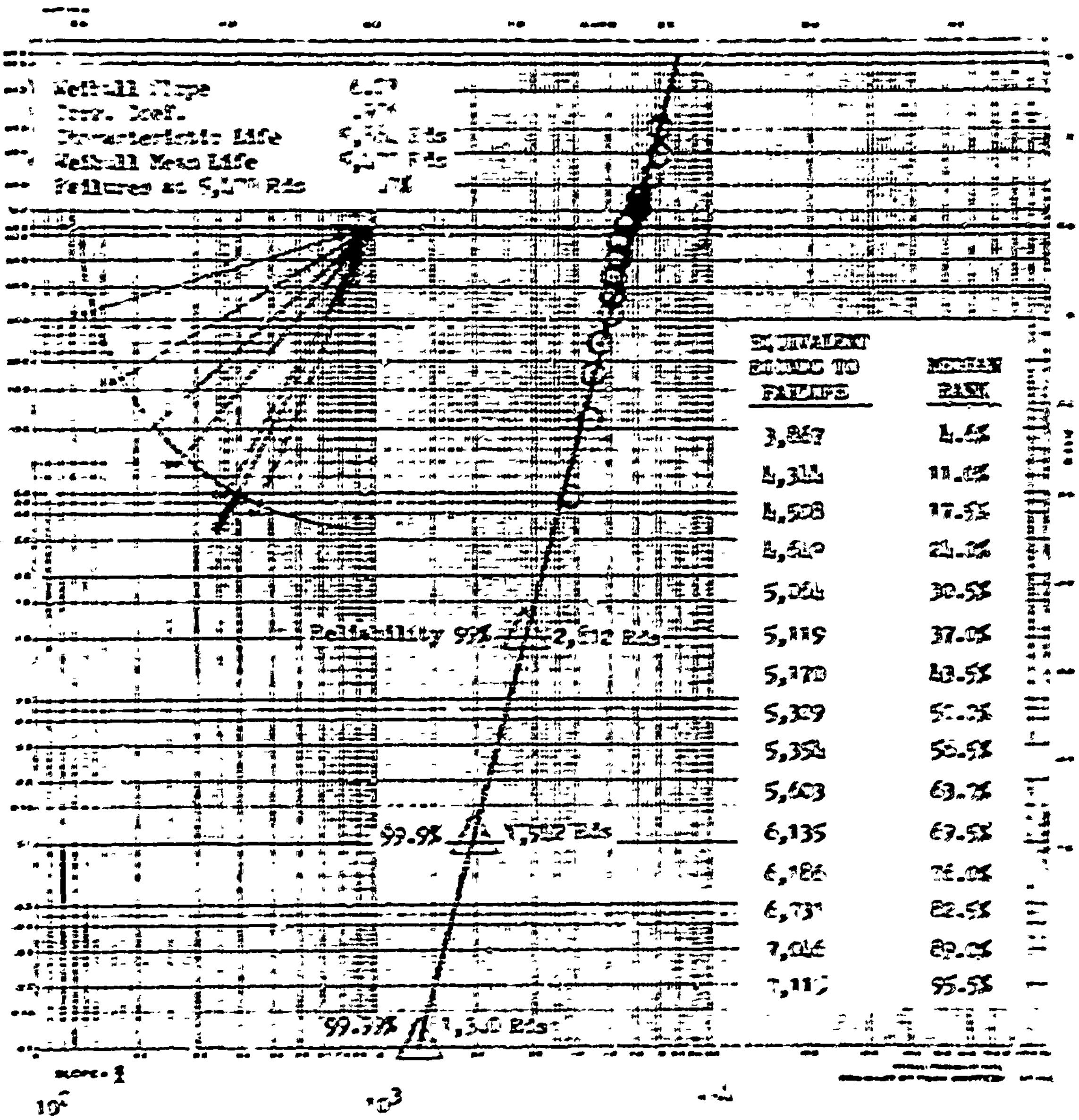
NO.		PAGE
1.	Graph - Reliability vs Equivalent Rounds to Failure	32
2.	Photos of Failed M14 Rifle Specimens	33-36

E

7.62MM 1.8 WALL RATED

15 - M14 RIFLE BARREL TEST SPECIMENS

ALL FIRED TO VARYING DEGREES AND THEN CYCLED TO FAILURE

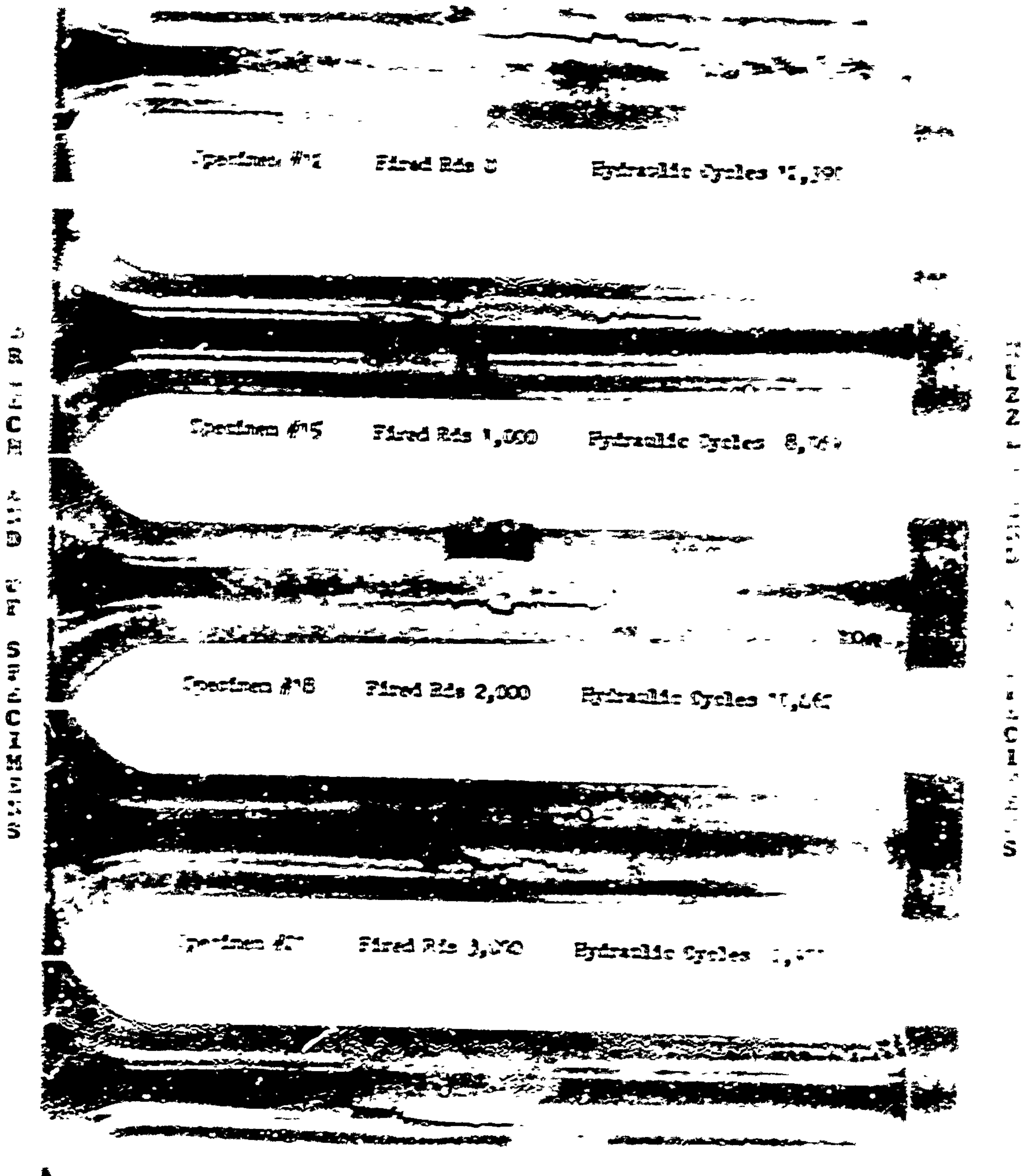


EQUIVALENT ROUNDS TO FAILURE	MEDIAN RANK
3,867	4.5%
4,314	11.0%
4,508	17.5%
4,610	24.0%
5,024	30.5%
5,119	37.0%
5,170	43.5%
5,329	50.0%
5,354	56.5%
5,603	63.0%
6,135	67.5%
6,186	76.0%
6,73[illegible]	82.5%
7,016	89.0%
7,11[illegible]	95.5%

EQUIVALENT ROUNDS TO FAILURE

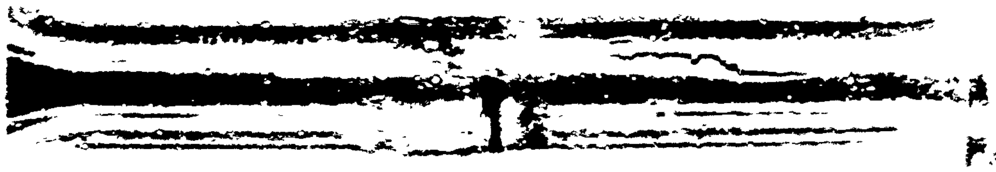
E

COMPARISON OF CRACK GEOMETRY AND LOCATION



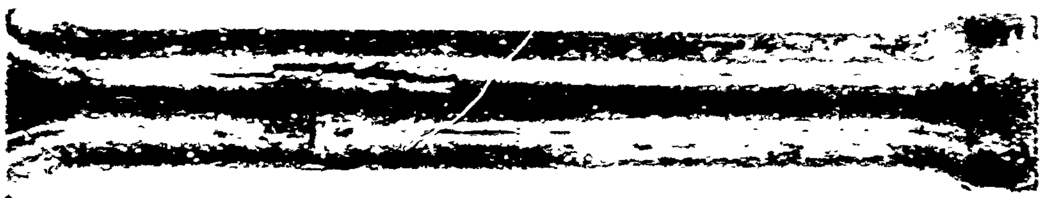
E

COMPARISON OF CRACK DENSITY AND LOCATION

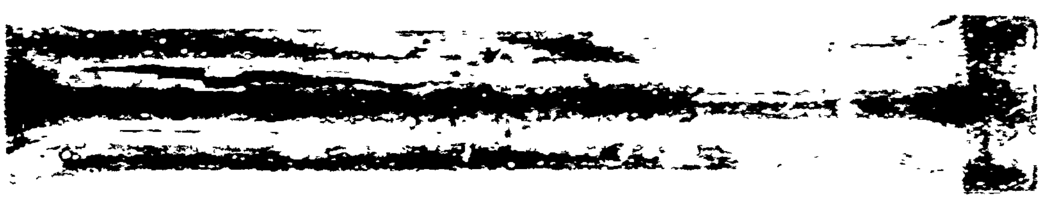


Specimen #13 Fired Rds 0 Hydraulic Cycles 15,552

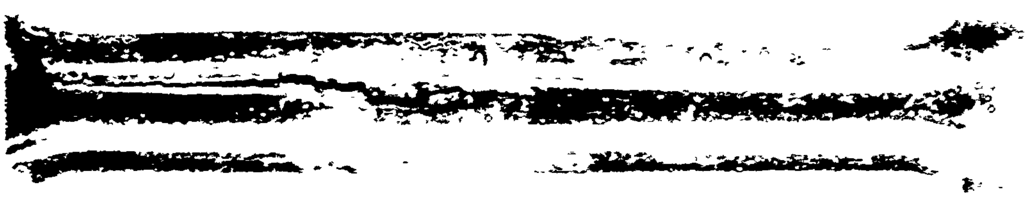
Specimen #[illegible] Fired Rds 1,000 Hydraulic Cycles 8,983



Specimen #[illegible] Fired Rds 2,000 Hydraulic Cycles 7,416



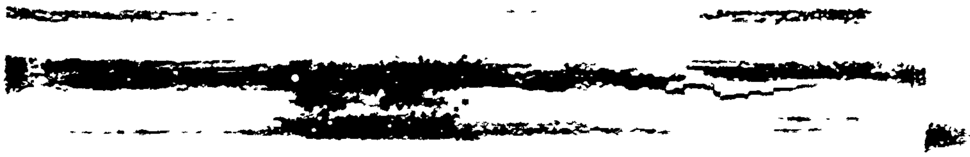
Specimen #[illegible] Fired Rds 3,[illegible] Hydraulic Cycles [illegible]



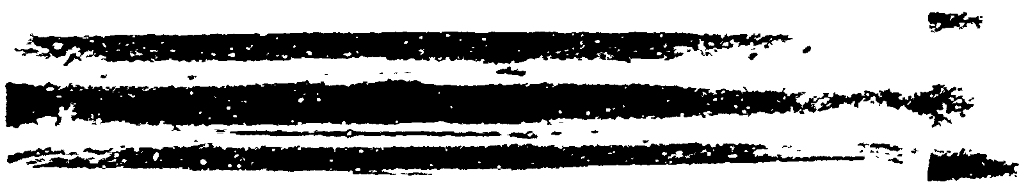
Specimen #[illegible] Fired Rds [illegible] Hydraulic Cycles [illegible]

E

COMPARISON OF CRACK GEOMETRY AND LOCATION

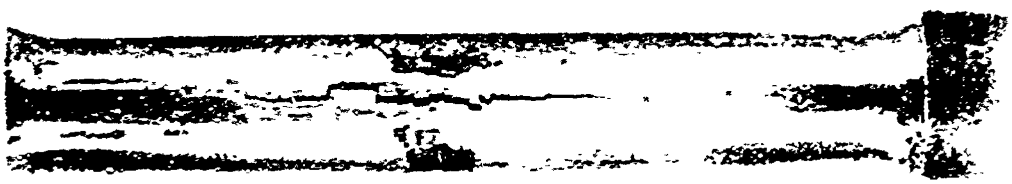


Specimen #14 Fired Rds 0 Hydraulic Cycles 8,552

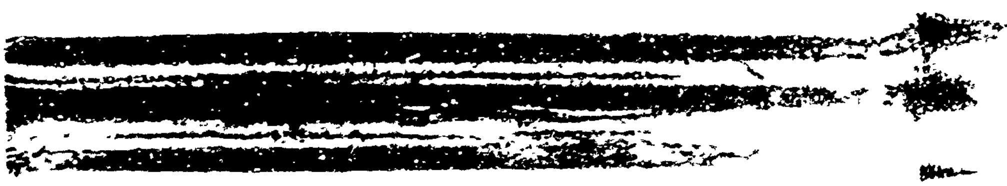


Specimen #17 Fired Rds 1,000 Hydraulic Cycles 11,355

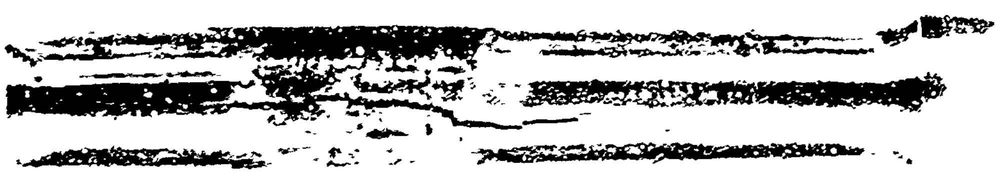
MUZZLE END



Specimen #20 Fired Rds 2,000 Hydraulic Cycles 5,546



Specimen #23 Fired Rds 3,000 Hydraulic Cycles 9,[illegible]



[illegible] Fired [illegible] Hydraulic Cycles [illegible]

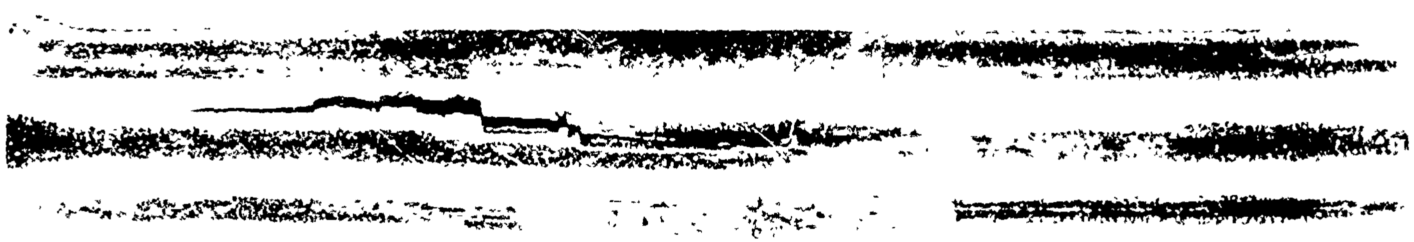
E

COMPARISON OF FAILURE BETWEEN A FIRED TO DESTRUCTION SPECIMEN AND A SPECIMEN HAVING A COMBINATION OF FIRING AND HYDRAULIC CYCLING TO DESTRUCTION

BREECH END OF SPECIMENS

MUZZLE END OF SPECIMENS

Specimen #31 **Fired Rds 9,869** Hydraulic Cycles 0



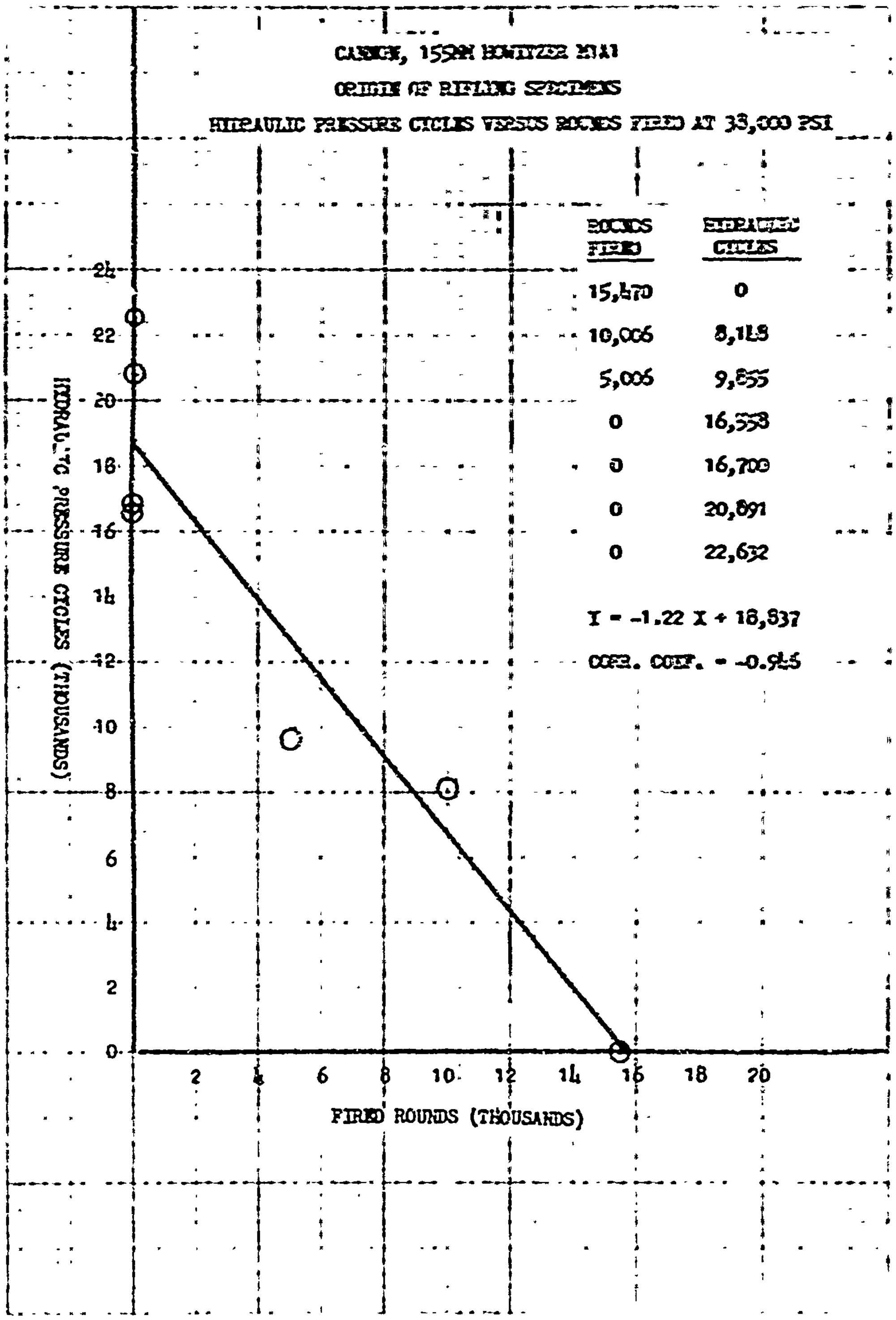
Specimen #24 Fired Rds 4,000 Hydraulic Cycles 2,739

APPENDIX F

APPLICATION OF MULTI-LEVEL TESTING TO STANDARD CANNON

NO.		PAGE
1.	Cannon 155MM Howitzer M1A1 Graph - Hydraulic Cycles vs Rounds Fired	38
2.	Cannon 155MM Howitzer M1A1 Graph - Reliability Predictions	39
3.	Cannon 175MM Guns M113 & M113A1 Graph - Hydraulic Cycles vs Rounds Fired	40
4.	Cannon 175MM Guns M113 & M113A1 Graph - Reliability Predictions	41

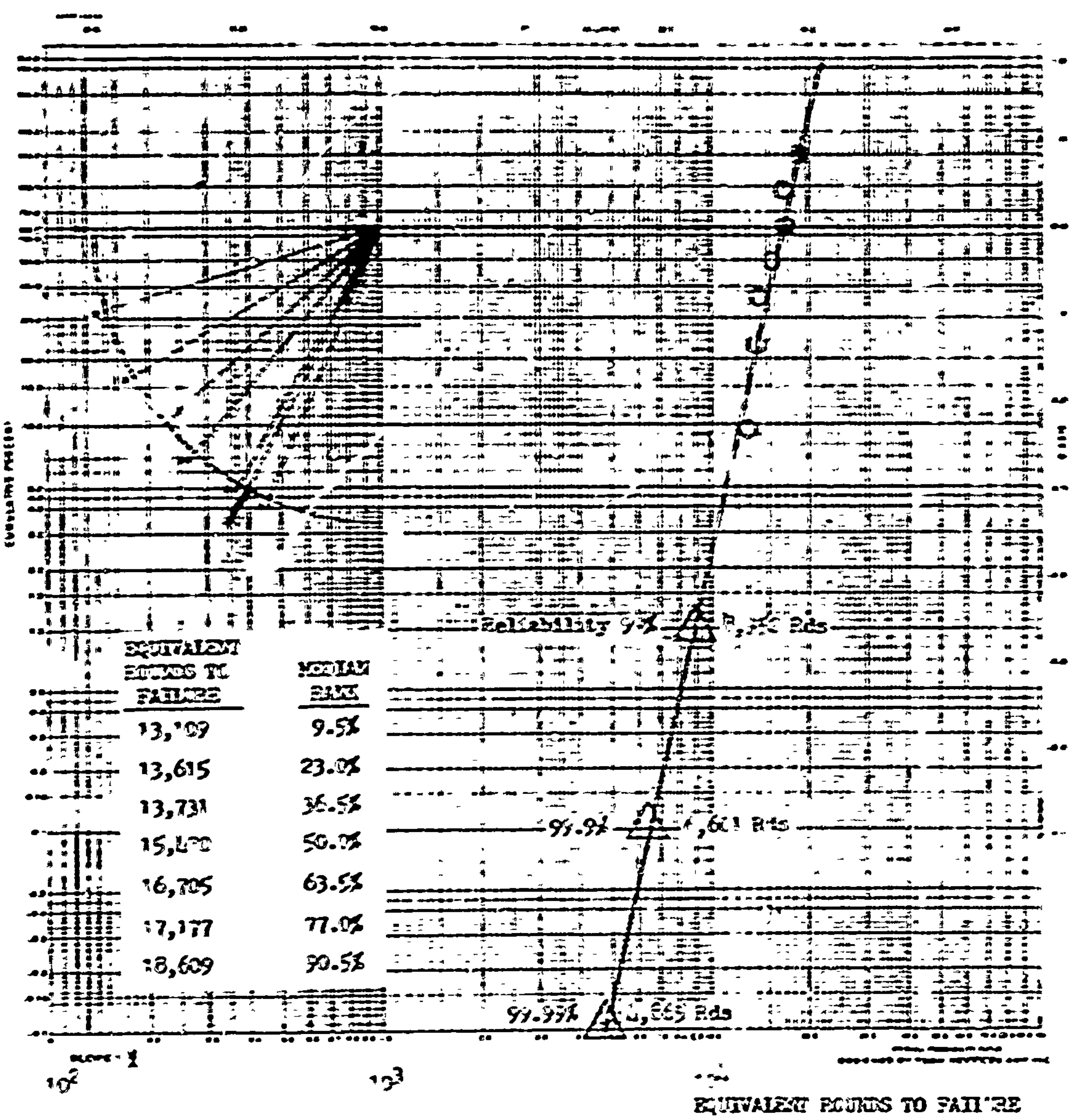
F


CANNON, 155MM HOWITZER M1A1
ORIGIN OF RIFLING SPECIMENS
HYDRAULIC PRESSURE CYCLES VERSUS ROUNDS FIRED AT 38,000 PSI
ROUNDS FIRED
HYDRAULIC CYCLES
15,470 0
10,006 8,118
5,006 9,855
0 16,558
0 16,700
0 20,891
0 22,632
Y = -1.22 X + 18,837
CORR. COEF. = -0.945
HYDRAULIC PRESSURE CYCLES (THOUSANDS)
FIRED ROUNDS (THOUSANDS)
0
2
4
6
8
10
12
14
16
18
20
22
24

CANNON, 155MM HOWITZER [illegible]

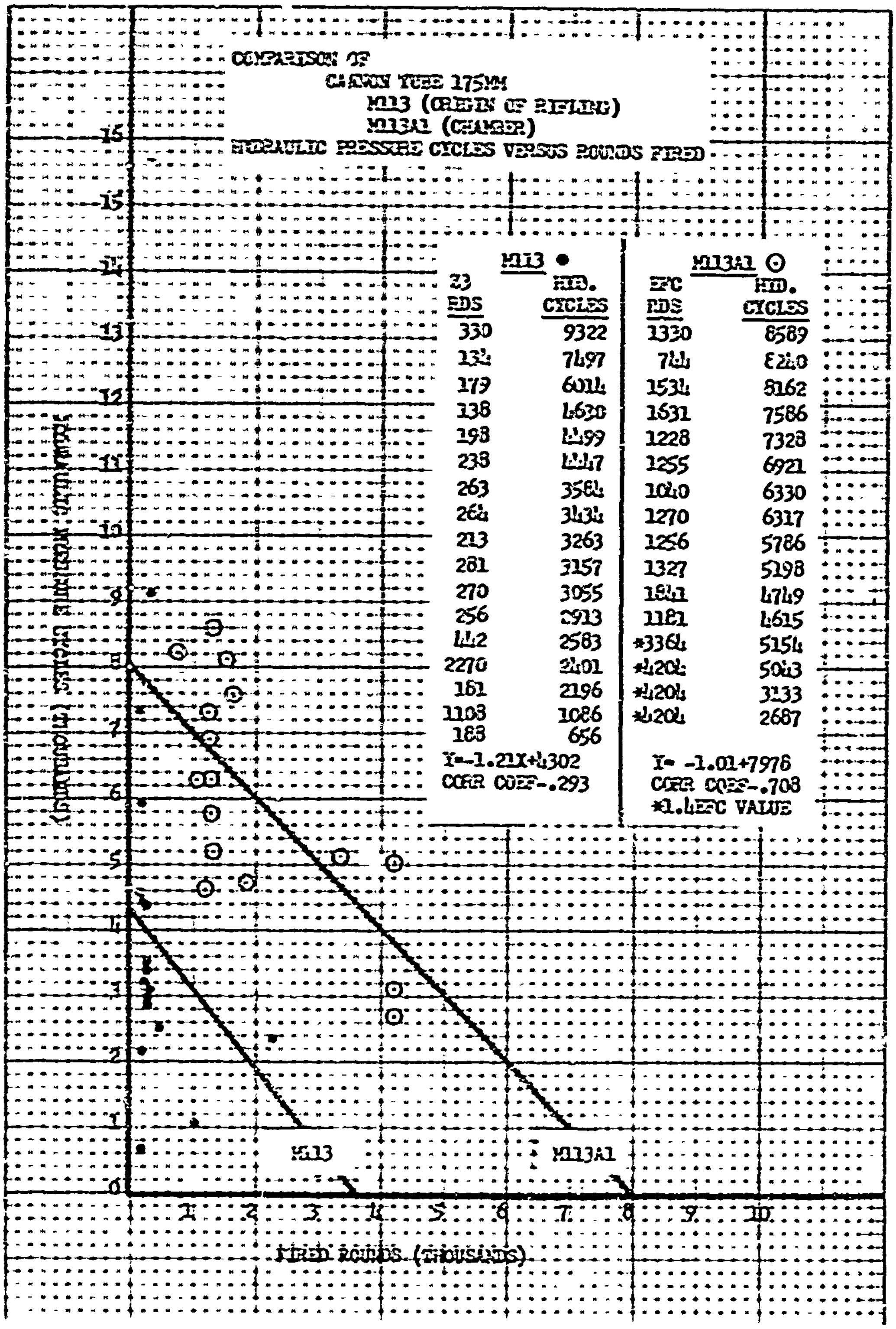
[illegible] OF RIFLING SPECIMENS

7 TESTED AT [illegible] PSI



EQUIVALENT ROUNDS TO FAILURE	MEDIAN RANK
13,[illegible]09	9.5%
13,615	23.0%
13,731	36.5%
15,[illegible]	50.0%
16,705	63.5%
17,177	77.0%
18,609	90.5%

F



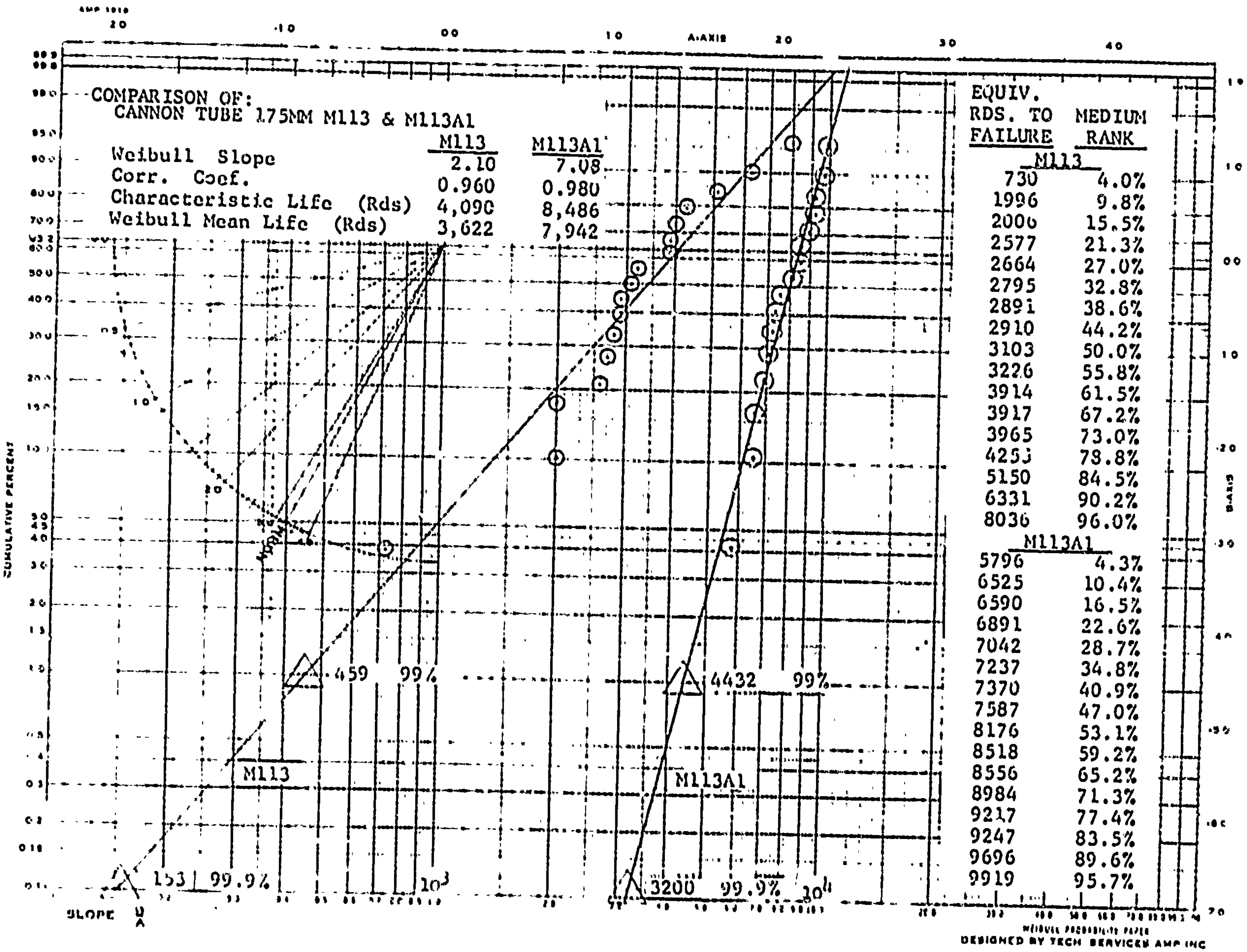
M113 ● ZF RDS	M113 ● HYD. CYCLES	M113A1 ⊙ EFC RDS	M113A1 ⊙ HYD. CYCLES
330	9322	1330	8589
134	7497	744	8240
179	6014	1534	8162
138	4630	1631	7586
198	4499	1228	7328
238	4447	1255	6921
263	3584	1040	6330
264	3434	1270	6317
213	3263	1256	5786
281	3157	1327	5198
270	3055	1841	4749
256	2913	1181	4615
442	2583	*3364	5154
2270	2401	*4204	5043
161	2196	*4204	3133
1103	1086	*4204	2687
183	656		

M113: Y=-1.21X+4302; CORR COEF-.293

M113A1: Y= -1.01+7976; CORR COEF-.708

*1.4EFC VALUE

F


COMPARISON OF:
CANNON TUBE 175MM M113 & M113A1
M113 M113A1
Weibull Slope 2.10 7.08
Corr. Coef. 0.960 0.980
Characteristic Life (Rds) 4,090 8,486
Weibull Mean Life (Rds) 3,622 7,942
EQUIV. RDS. TO FAILURE MEDIUM RANK
M113
730 4.0%
1996 9.8%
2006 15.5%
2577 21.3%
2664 27.0%
2795 32.8%
2891 38.6%
2910 44.2%
3103 50.0%
3226 55.8%
3914 61.5%
3917 67.2%
3965 73.0%
4253 78.8%
5150 84.5%
6331 90.2%
8036 96.0%
M113A1
5796 4.3%
6525 10.4%
6590 16.5%
6891 22.6%
7042 28.7%
7237 34.8%
7370 40.9%
7587 47.0%
8176 53.1%
8518 59.2%
8556 65.2%
8984 71.3%
9217 77.4%
9247 83.5%
9696 89.6%
9919 95.7%
459 99%
4432 99%
M113
M113A1
153 99.9%
3200 99.9%
10^3
10^4
MEAN
A-AXIS
B-AXIS
CUMULATIVE PERCENT
SLOPE
WEIBULL PROBABILITY PAPER
DESIGNED BY TECH SERVICES AMP INC

G

APPENDIX G

(PHASE III)

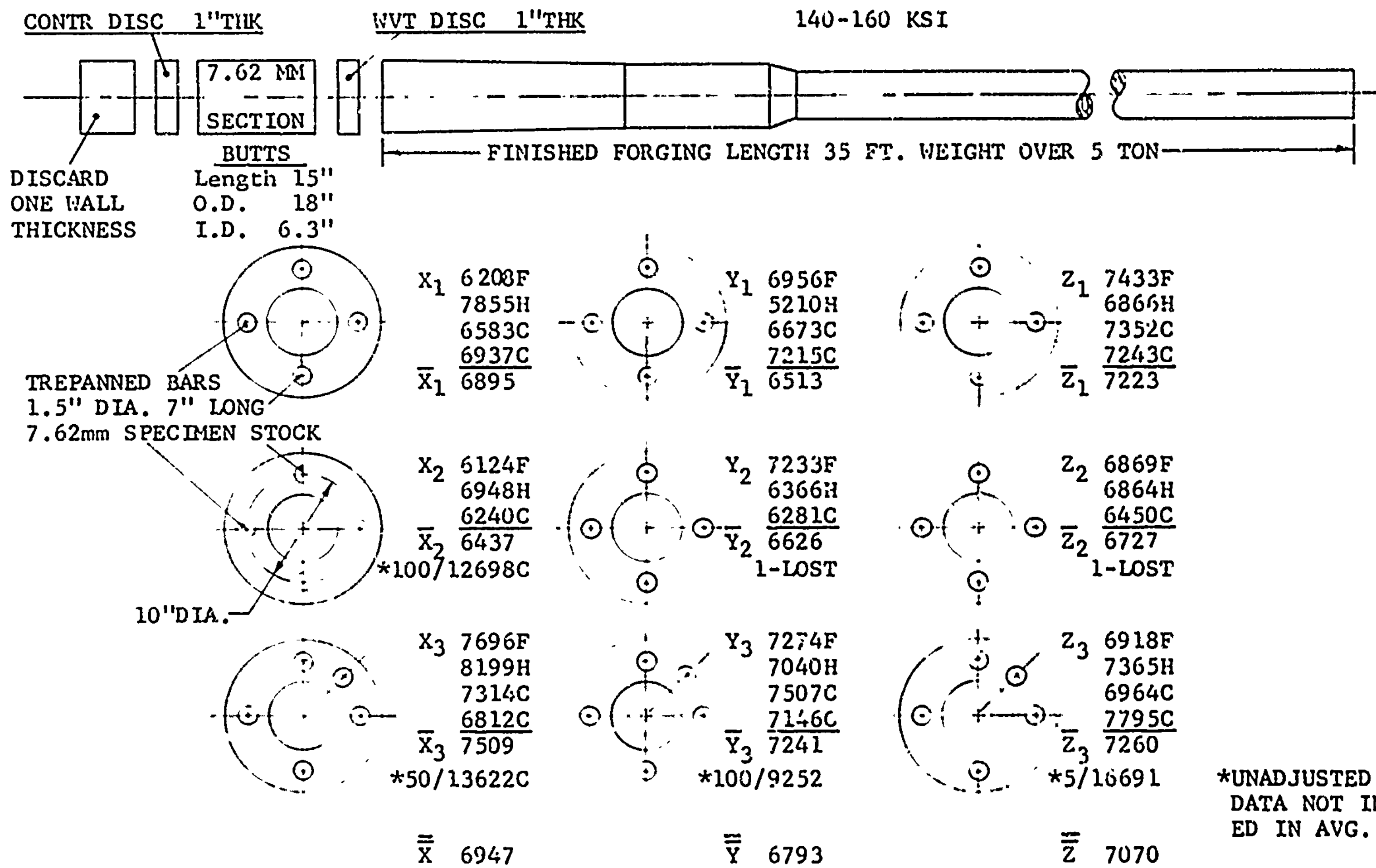
COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

NO.		PAGE
1.	Specimen Selection 175MM M113A1 Forging Material	43
2.	Phase III Test Plan	44

7.62mm LIFE TEST

USING 175mm M113A1 CANNON TUBE FORGING STEEL FROM THREE SUPPLIERS X,Y,Z, WITH THREE FORGINGS FROM EACH SUPPLIER AND THREE TO FIVE 7.62mm SPECIMENS FROM EACH FORGING.



*UNADJUSTED RAW DATA NOT INCLUDED IN AVG.

G

PHASE III

TEST PLAN

FOR 7.62MM SPECIMENS, 175MM TUBE MATERIAL

CATEGORY	QTY	TYPE TEST
PURE	9	HYDRAULIC PRESSURE CYCLED
SPECIAL	1	5 RDS/CYCLED
4 COMBINATION	1	50 RDS/CYCLED
	2	100 RDS/CYCLED
	3	500 RDS/CYCLED
	3	2000 RDS/CYCLED
15 COMBINATION	3	3000 RDS/CYCLED
	3	4000 RDS/CYCLED
	3	5000 RDS/CYCLED
REAL	9	FIRED
TOTAL	37	

H

APPENDIX H

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED BY THREE CONTRACTORS X, Y, Z.

NO.		PAGE
1.	Original Data - 175MM M113E1 Cannon Tube Material	46
2.	Graph - Hydraulic Cycles vs Rounds Fired 175MM M113E1 Cannon Tube Material	47

ORIGINAL DATA

7.62MM, 1.8 WALL RATIO SPECIMENS

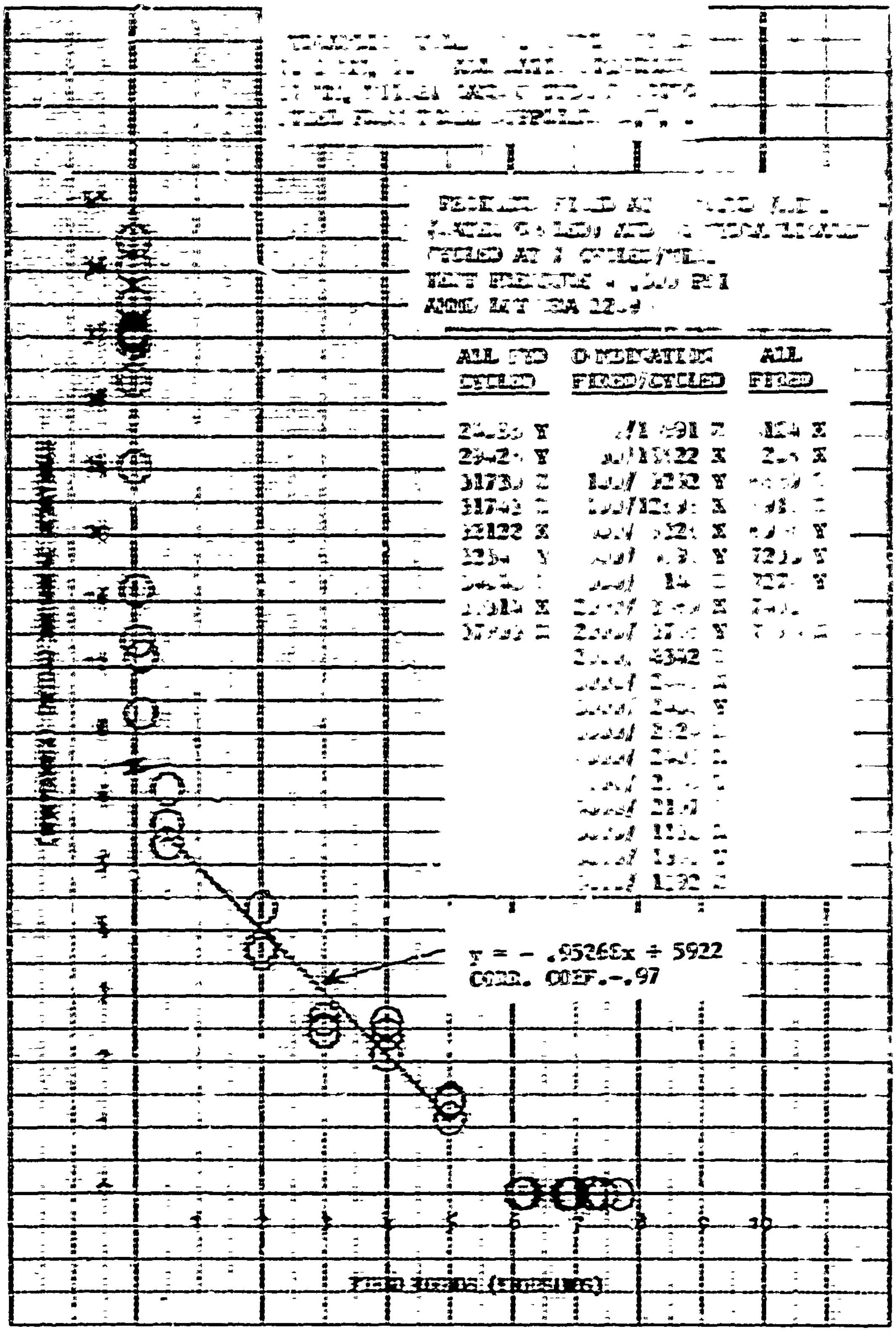
175MM, M113E1 CANNON TUBE FORGING

STEEL FROM TIRE; SUPPLIERS X, Y, Z

FORGING SUPPLIER	X			Y			Z		
SPECIMEN TREATMENT	SPECIMEN NUMBER	FORGING IDENTITY	UNALTERED DATA	SPECIMEN NUMBER	FORGING IDENTITY	UNALTERED DATA	SPECIMEN NUMBER	FORGING IDENTITY	UNALTERED DATA
ALL FIRED	1	X_1	6808	13	Y_1	6956	25	Z_1	7431
	5	X_2	6124	17	Y_2	7233	30	Z_2	6062
	9	X_3	7696	21	Y_3	7274	33	Z_3	6910
ALL CYCLED	2	X_1	36314	14	Y_1	24683	26	Z_1	31743
	6	X_2	32122	19	Y_2	29420	31	Z_2	31734
	10	X_3	37903	22	Y_3	32546	34	Z_3	34648
** COMBINATION FIRED AND HYDRAULIC CYCLED	3	X_1	2000/ 3609	15	Y_1	2000/ 3740	27	Z_1	2000/ 4362
	4	X_1	5000/ 1132	16	Y_1	5000/ 1360	28	Z_1	5000/ 1392
	7	X_2	3000/ 2445	20	Y_2	3000/ 2460	32	Z_2	3000/ 2624
	8	X_2	*100/12698	18	Y_2	Lost	29	Z_2	Lost
	11	X_3	4000/ 2405	23	Y_3	4000/ 6560	35	Z_3	4000/ 2167
	12	X_3	500/ 5326	24	Y_3	500/ 5596	36	Z_3	500/ 6148
	37	X_3	* 50/13622	38	Y_3	*100/ 9252	39	Z_4	* 5/16621

* Special Tests to show effect of firing damage on life reduction (See Graph)

** Only combination fired and hydraulic cycled data was used to generate the straight line relationship y = -.05260x + 5022 (excluding the 4 special test data points)


y = - .95268x + 5922
CORR. COEF.-.97

APPENDIX I

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

No.		PAGE
1.	Transformation of Data to an All Fired Base	49
2.	Adjusted Life Data	50

TRANSFORMATION OF DATA TO AN ALL FIRED BASE

A	B	C	D	E	F
ALL FIRED	ALL HYD CYCLED	ALL HYD CYCLED ADJUSTED	COMBINATION FIRED/CYCLED	COMBINATION EQUIV. FIRED	COMBINATION EQUIV. FIRED ADJUSTED
6124	24088	5210	3000/2445	5566	6240
6208	29428	6366	3000/2480	5603	6281
6869	31730	6864	3000/2624	5754	6450
6918	31743	6866	2000/3689	5872	6583
6956	32122	6948	2000/3765	5952	6673
7233	32546	7040	500/5326	6091	6828
7274	34048	7365	5000/1132	6188	6937
7433	36314	7855	4000/2107	6212	6964
7696	37903	8199	500/5596	6374	7146
$\bar{A}$ 6968	$\bar{B}$ 32214	$\bar{C}$ 6968	5000/1368	6436	7215
			5000/1392	6461	7243
			4000/2405	6524	7314
			2000/4342	6558	7352
			4000/2568	6696	7507
			500/6148	6953	7295
				$\bar{E}$ 6216	$\bar{F}$ 6969

$C=(\bar{A}/\bar{B})\ B$

$E=D_{fired}+(D_{cycled}/.95268)$

$F=(\bar{A}/\bar{E})\ E$

(y)CYCLED/(x) FIRED RELATIONSHIP

$y=-.95268x+5922$

7.62MM, 1.8 WALL RATIO SPECIMEN FATIGUE FAILURE DATA
175MM, M113E1 CANNON TUBE FORGING STEEL FROM THREE SUPPLIERS X,Y,Z

ADJUSTED LIFE DATA

FORGING SUPPLIER	X			Y			Z		
SPECIMEN TREATMENT	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA	SPECIMEN NUMBER	FORGING IDENTITY	ADJUSTED DATA
ALL FIRED	1 5 9	X_1 X_2 X_3	6208 6124 7696	13 17 21	Y_1 Y_2 Y_3	6956 7233 7274	25 30 33	Z_1 Z_2 Z_3	7433 6869 6918
ADJUSTED ALL CYCLED	2 6 10	X_1 X_2 X_3	7855 6948 8199	14 19 22	Y_1 Y_2 Y_3	5210 6366 7040	26 31 34	Z_1 Z_2 Z_3	6866 6864 7365
ADJUSTED COMBINATION FIRED AND CYCLED	3 4 7 11 12	X_1 X_1 X_2 X_3 X_3	6583 6937 6240 7314 6828	15 16 20 23 24	Y_1 Y_1 Y_2 Y_3 Y_3	6673 7215 6281 7507 7146	27 28 32 35 36	Z_1 Z_1 Z_2 Z_3 Z_3	7352 7243 6450 6964 7795

ANALYSIS OF VARIANCE

		F-RATIO
ALL ADJUSTED	X	2.11
ALL ADJUSTED	Y	1.81
ALL ADJUSTED	Z	.009
ALL FIRED	XYZ	.65
ALL ADJ CYCLED	XYZ	3.56
ALL ADJ COMBO	XYZ	.84
TABLE VALUE		5.14

In order to simplify, adjusted combination fired and cycled X_1's, X_3's, Y_1's, Y_3's etc. were averaged to provide three replicates per cell.

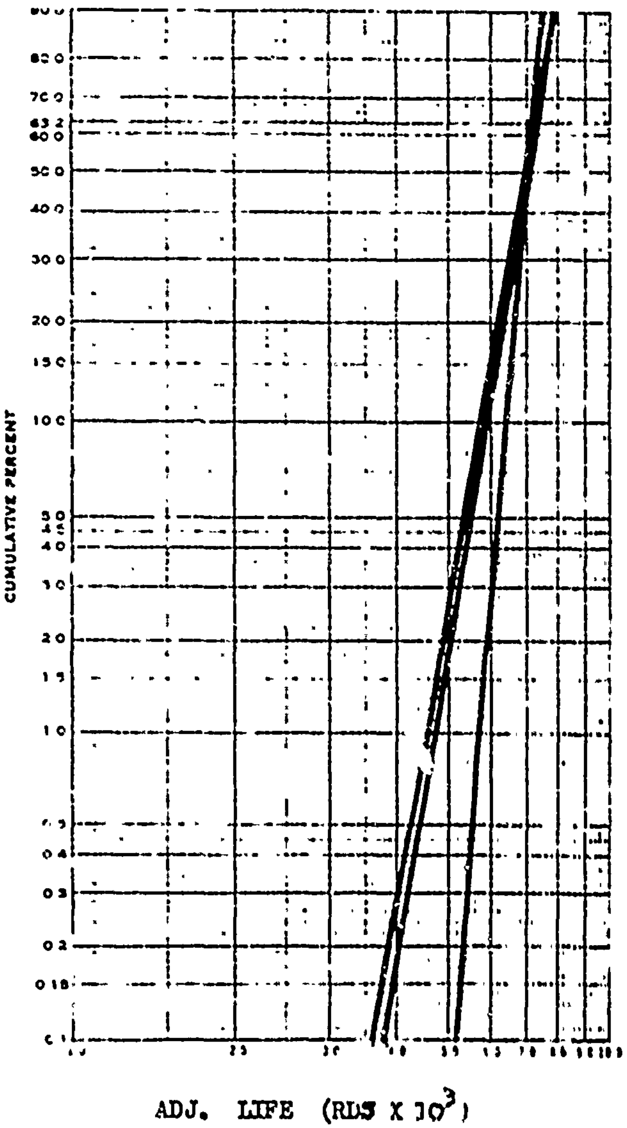
APPENDIX J

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED

BY THREE CONTRACTORS X, Y, Z.

NO.		PAGE
1.	Life Characteristic Comparison by Material Supplier (Using Adjusted Data)	52
2.	Life Characteristics Comparison by Test Method (Using Adjusted Lives)	53
3.	Graph - Reliability Prediction (Using All Adjusted Data)	54



COMPARISON BY FORGING MATERIAL SUPPLIERS X,Y,Z.

7.62 MM, 1.8 WALL RATIO LIFE TEST DATA

175 MM, M113E1 CANNON TUBE FORGING MATERIAL

FORGING MANUFACTURER		X	Y	Z
CORR. COEF		.948	.947	.946
WEIBULL SLOPE		10.7	10.2	20.2
% FAILED AT WEIBULL MEAN LIFE		45	45	44
WEIBULL MEAN LIFE		6976	6793	7088
CHARACTERISTIC LIFE 63.2%		7313	7134	7280
RELIABILITY	99 %	4758	4554	5797
	99.9%	3835	3635	5171
MEDIAN RANK	93.9%	8199H	7507C	7795C
	85.1%	7855H	7274F	7433F
	76.3%	7696F	7233F	7365H
	67.5%	7314C	7215C	7352C
	58.8%	6948H	7146C	7243C
	50.0%	6937C	7040H	6964C
	41.2%	6828C	6956F	6918F
	32.5%	6583C	6673C	6869F
	23.7%	6240C	6366H	6866H
	14.9%	6208F	6281C	6864H
	6.1%	6124F	5210H	6450C

F FIRED
C COMBINATION FIRED/HYDRAULIC CYCLED
H HYDRAULIC CYCLED
NOTE: DATA TRANSFORMED TO AN ALL FIRED BASE

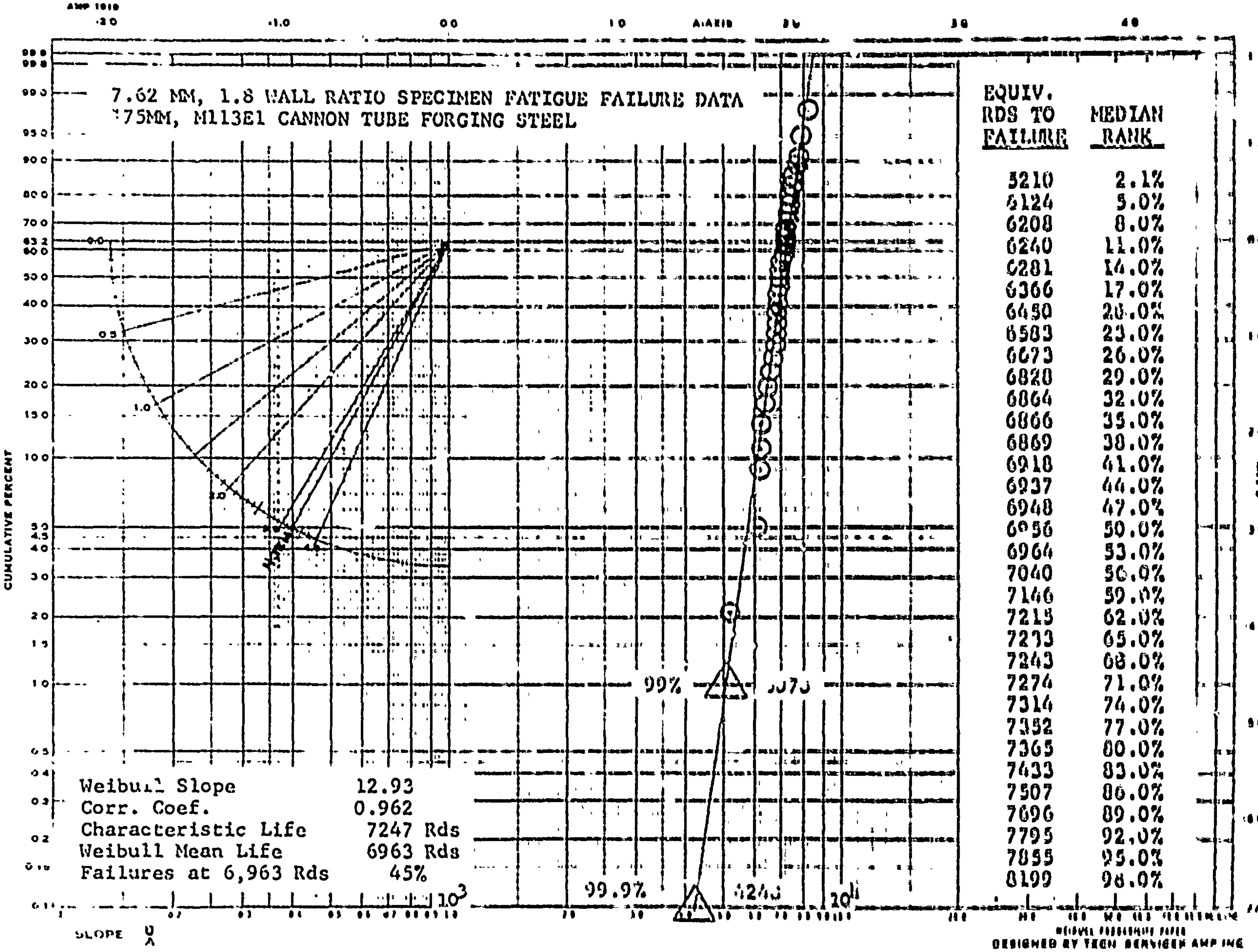
7.62MM, 1.8 WALL RATIO LIFE TEST COMPARISONS

175MM, M113E1 CANNON TUBE FORGING MATERIAL

	COMBINATION FIRED/CYCLED (ADJ)				ALL FIRED	ALL DATA
FORGING SUPPLIER	X_5*	Y_5	Z_5	XYZ_{15}	XYZ_9	XYZ_{33}
HYDRAULIC TO FIRED SLOPE	-.888	-.891	-1.079	-.953		
CORR. COEF	-.979	-.969	-.982	-.970		
WEIBULL SLOPE	17.12	14.27	14.44	16.96	13.99	12.93
CORR. COEF	.985	.980	.904	.977	.974	.962
% FAILED AT WEIBULL MEAN LIFE	44	45	45	44	45	45
WEIBULL MEAN LIFE	6754	6934	7130	6956	6948	6963
RELIABILITY 99.9%	4655	4434	4582	4777	4402	4248

*X_5 - CONTRACTOR X, FIVE SPECIMENS

7.62 MM, 1.8 WALL RATIO SPECIMEN FATIGUE FAILURE DATA
175MM, M113E1 CANNON TUBE FORGING STEEL



EQUIV. RDS TO FAILURE	MEDIAN RANK
5210	2.1%
6124	5.0%
6208	8.0%
6240	11.0%
6281	14.0%
6366	17.0%
6450	20.0%
6583	23.0%
6673	26.0%
6820	29.0%
6864	32.0%
6866	35.0%
6869	38.0%
6918	41.0%
6937	44.0%
6948	47.0%
6956	50.0%
6964	53.0%
7040	56.0%
7146	59.0%
7215	62.0%
7233	65.0%
7243	68.0%
7274	71.0%
7314	74.0%
7352	77.0%
7365	80.0%
7433	83.0%
7507	86.0%
7696	89.0%
7795	92.0%
7855	95.0%
8199	98.0%

Weibull Slope	12.93
Corr. Coef.	0.962
Characteristic Life	7247 Rds
Weibull Mean Life	6963 Rds
Failures at 6,963 Rds	45%

K

APPENDIX K

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED BY THREE CONTRACTORS X, Y, Z.

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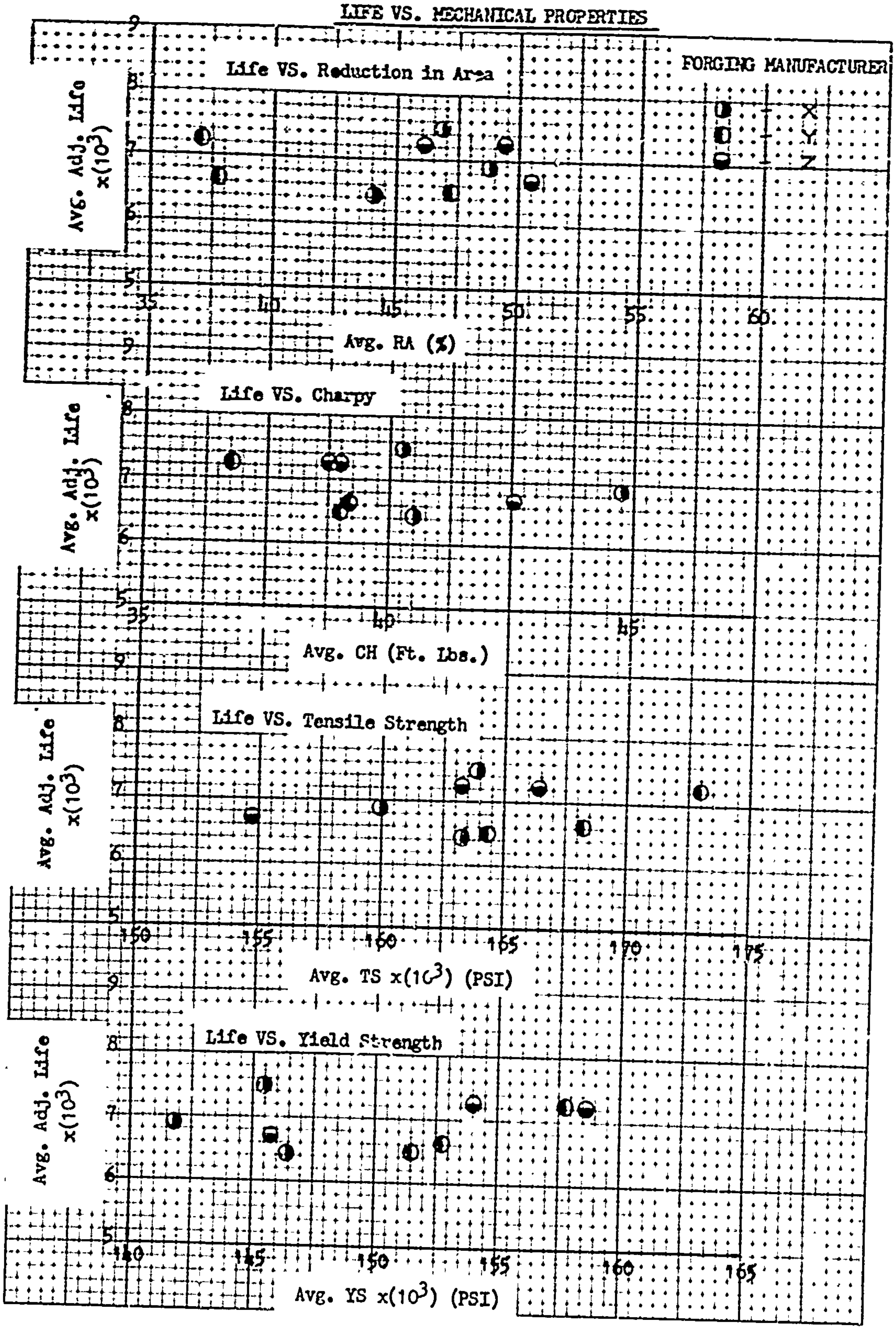
1.	Material Properties	56
2.	Life vs Mechanical Properties	57
3.	Adjusted Life vs Material Supplier	58

MATERIAL PROPERTIES

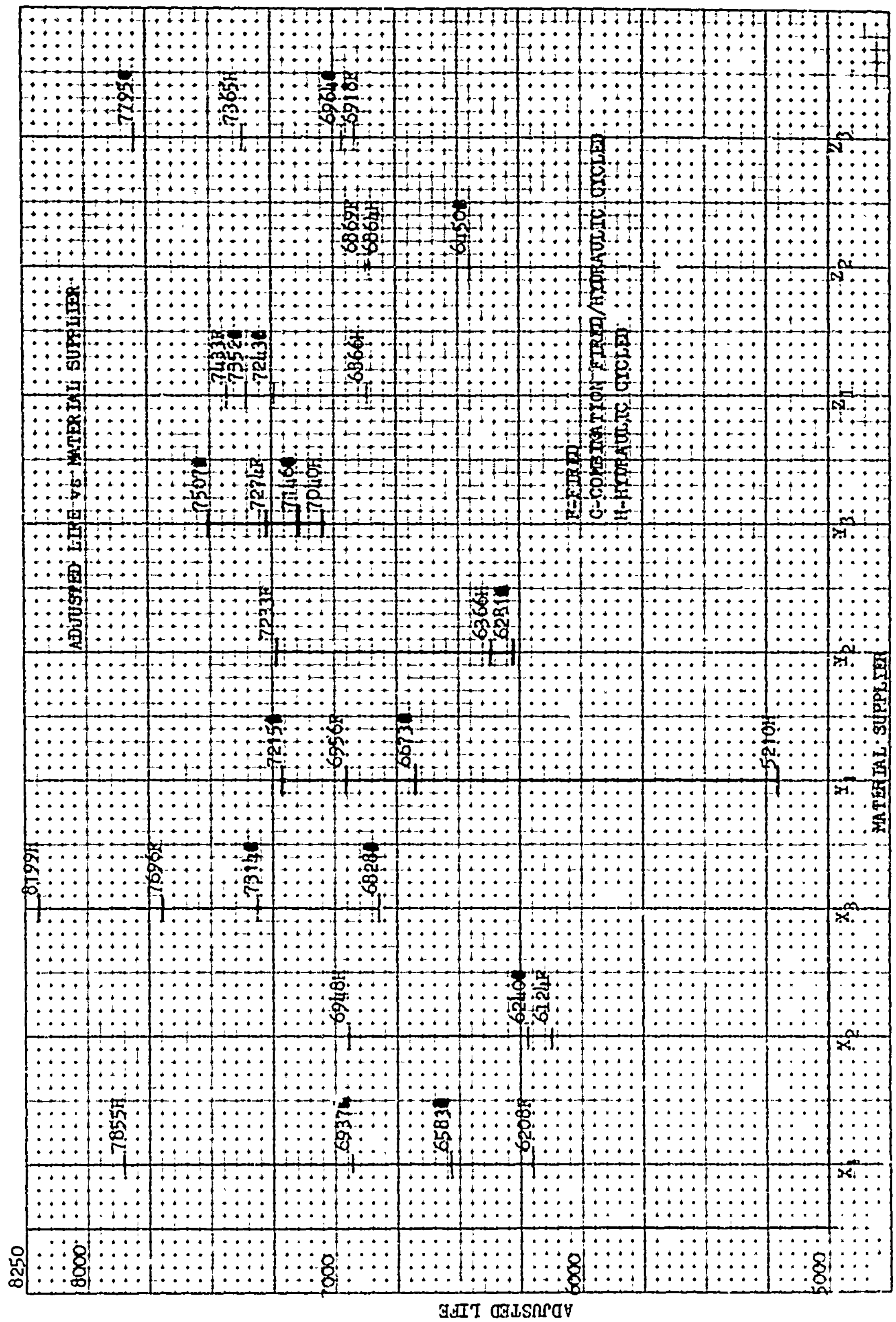
TUBE FORGING CODE	MECHANICAL PROPERTIES *AVERAGE YSx10^3	RA%	CH-40°	TSx10^3	EL%	CHEMICAL COMPOSITION C	Mn	P	S	Si	Ni	Cr	Mo	V	SPECIMEN NO.	R_c	LIFE TEST FIRED	LIFE DATA CYCLED	ADJ. LIFE	ADJ AVE. LIFE
X_1	142.0	46.9	46.0	160.0	15.5										1	34	6208	0	6208	
	141.0	50.8	43.0	159.0	17.0	.36	.42	.007	.009	.06	3.30	0.92	.66	.09	2	35	0	36,314	7855	6825
	142.0	47.7	45.0	160.5	14.5										3	36	2000	3,689	6583	
	142.0	49.5	45.0	160.0	16.0										4	35	5000	1,132	6937	
	141.75*	48.72*	44.75*	159.88*	15.75*															
X_2	147.0	46.6	41.0	164.0	16.0										5	35	6124	0	6124	
	145.0	41.6	40.0	162.5	15.0	.37	.48	.008	.014	.01	3.25	0.82	.66	.08	6	35	0	32,122	6948	6437
	147.5	43.1	41.0	164.0	15.0										7	34	3000	2,145	6240	
	145.5	44.9	40.0	162.5	15.0										8	36	100	12,689		
	146.38*	44.05*	40.50*	163.25*	15.25*															
X_3	146.5	46.6	40.0	164.5	15.5										9	36	7676	0	7676	
	144.5	48.0	41.0	163.5	15.0	.37	.44	.008	.015	.03	3.28	0.84	.64	.12	10	36	0	37,903	8197	7507
	146.0	46.0	40.0	164.5	16.0										11	36	4000	2,405	7314	
	144.5	46.9	40.0	163.0	16.5										12	37	500	5,326	6870	
	145.38*	46.87*	40.25*	163.88*	15.75*										37	34	50	13,663		
Y_1	151.0	48.7	38.5	161.5	14.9										13	36	6956	0	6956	
	151.0	45.5	39.5	165.0	14.1	.33	.58	.015	.004	.37	3.04	0.74	.54	.08	14	35	0	24,008	5210	6513
	151.0	47.1	38.0	164.0	13.4										15	36	2000	3,765	6673	
	153.0	47.5	40.0	167.0	13.5										16	37	5000	1,368	7215	
	151.50*	47.20*	39.00*	164.38*	13.97*															
Y_2	154.0	33.8	38.0	168.0	12.1										17	36	7233	0	7233	
	153.0	38.2	42.5	167.0	11.5	.33	.62	.013	.004	.36	3.01	0.78	.54	.09	19	36	0	29,428	6366	6626
	154.0	47.5	41.5	168.0	11.4										20	36	3000	2,480	6781	
	150.0	31.8	34.5	170.0	10.1															
	152.75*	37.82*	39.13*	168.25*	11.27*															
Y_3	160.0	40.9	36.0	176.0	13.1										21	37	7274	0	7274	
	157.0	37.8	38.0	173.0	12.3	.33	.53	.013	.003	.34	3.05	0.75	.55	.08	22	37	0	32,546	7043	7241
	157.0	34.3	38.0	170.0	12.0										23	37	4000	2,560	7507	
	157.0	35.2	35.5	173.0	11.5										24	36	500	5,596	7146	
	157.75*	37.17*	36.88*	173.00*	12.32*										18	36	100	9,252		
Z_1	157.0	47.3	35.0	165.0	16.4										25	35	7433	0	7433	
	159.0	49.7	41.0	168.0	16.4	.31	.42	.008	.007	.08	3.12	1.14	.54	.12	26	37	0	31,743	6866	7223
	159.5	39.7	34.5	166.5	14.3										27	38	2000	4,342	7352	
	159.0	48.5	41.5	166.0	17.1										28	37	5000	1,392	7243	
	158.63*	46.30*	39.00*	166.38*	16.05*															
Z_2	150.0	49.3	41.5	153.0	15.0										30	33	6869	0	6869	
	147.0	52.5	44.0	155.0	17.1	.27	.34	.010	.009	.02	3.10	1.11	.54	.11	31	34	0	31,738	6064	6427
	140.0	50.1	42.5	150.0	15.7										32	35	3000	2,624	6450	
	146.0	50.5	42.5	155.0	16.4															
	145.75*	50.60*	42.63*	154.75*	16.05*															
Z_3	156.0	47.7	37.5	165.0	17.1										33	33	6918	0	6918	
	157.0	47.7	38.0	166.0	15.7	.36	.34	.008	.009	.02	3.06	1.12	.54	.12	34	36	0	34,048	7365	7260
	151.0	52.9	39.5	160.0	16.4										35	36	4000	2,107	6964	
	152.0	49.2	40.0	162.0	17.1										36	35	500	8,148	7795	
	154.00*	49.40*	38.75*	163.25*	16.57*										39	36	5	16,691		

K



LIFE VS. MECHANICAL PROPERTIES
Life VS. Reduction in Area
FORGING MANUFACTURER
X
Y
Z
Avg. Adj. Life x(10^3)
Avg. RA (%)
Life VS. Charpy
Avg. CH (Ft. Lbs.)
Life VS. Tensile Strength
Avg. TS x(10^3) (PSI)
Life VS. Yield Strength
Avg. YS x(10^3) (PSI)

K


ADJUSTED LIFE vs MATERIAL SUPPLIER
F=FIRED
C-COMBINATION FIRED/HYDRAULIC CYCLED
H-HYDRAULIC CYCLED
ADJUSTED LIFE
MATERIAL SUPPLIER
8250
8000
7000
6000
5000
X1
X2
X3
Y1
Y2
Y3
Z1
Z2
Z3
7855H
6937
6583
6208H
6948H
6240
6124F
8199H
7696F
7314
6828
7215
6956F
6673
5210H
7233F
6366H
6281
7507
7271F
7146
7040H
7433F
7352
7243
6866H
6869F
6864H
6450
7795
7365H
6964
5918F

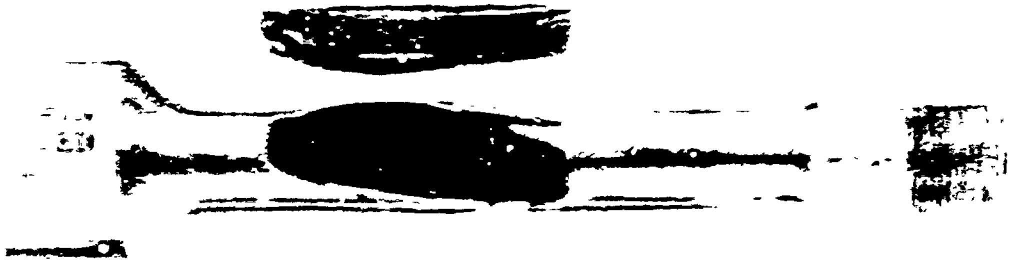
APPENDIX L

(PHASE III)

COMPARISON OF 175MM TUBE FORGING MATERIAL PRODUCED BY THREE CONTRACTORS X, Y, Z.

NO.		PAGE
1.	Photos of Specimens Fired to Destruction Material Supplier X	60
2.	Photos of Specimens Fired to Destruction Material Supplier Y	61
3.	Photos of Specimens Fired to Destruction Material Supplier Z	62


FIRED




FIRED


FIRED

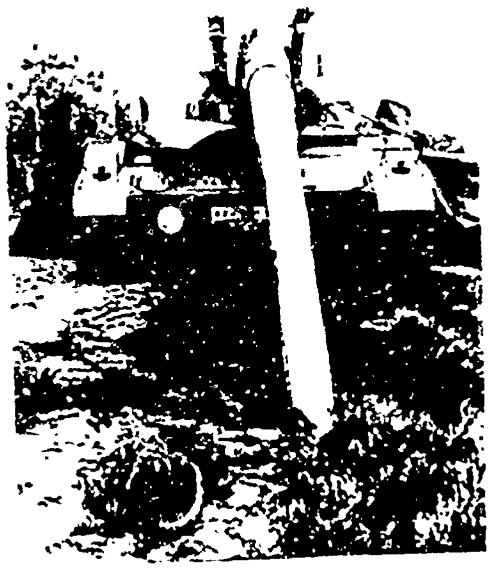
M

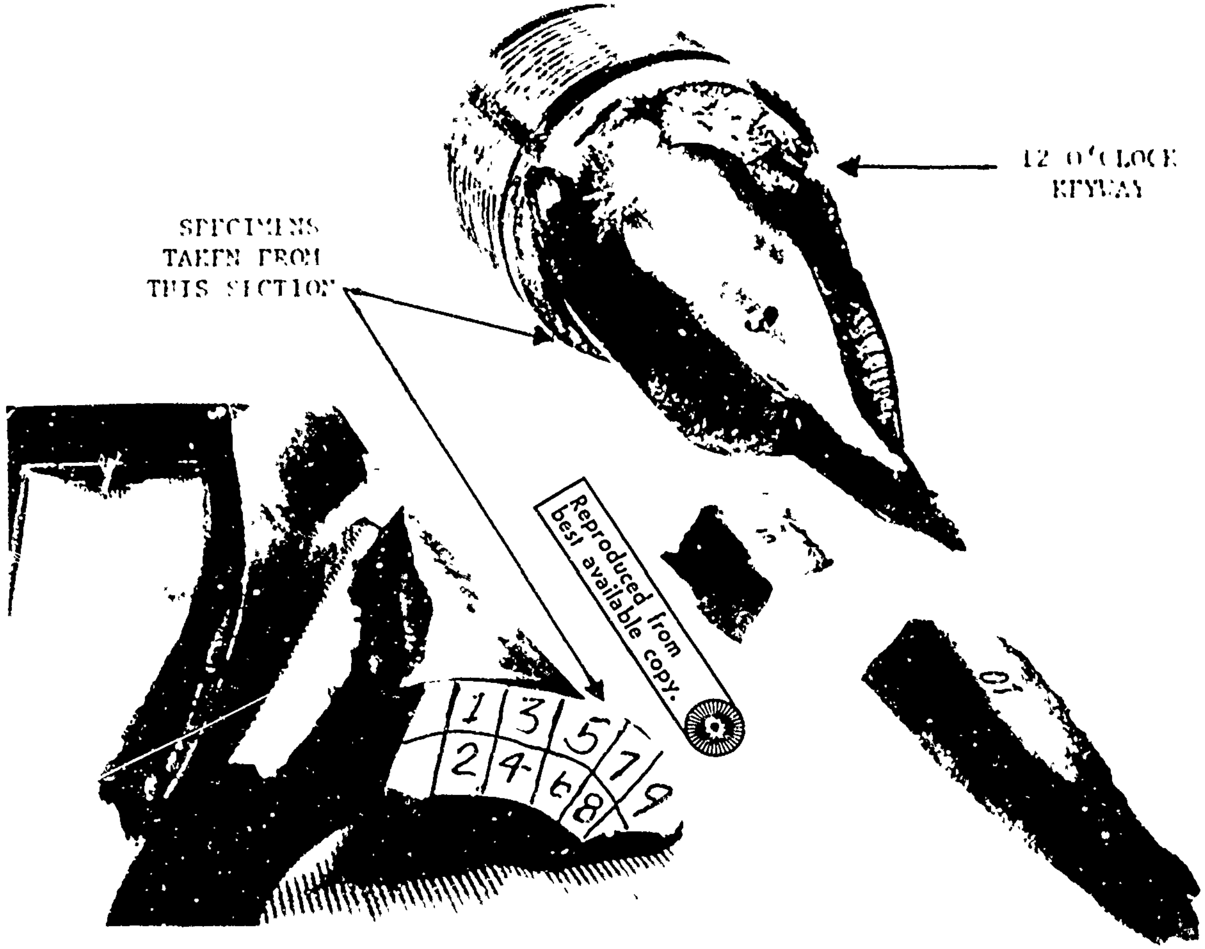
APPENDIX M

APPLICATION OF 7.62MM BARREL SPECIMENS TO A FIELD FAILURE PROBLEM

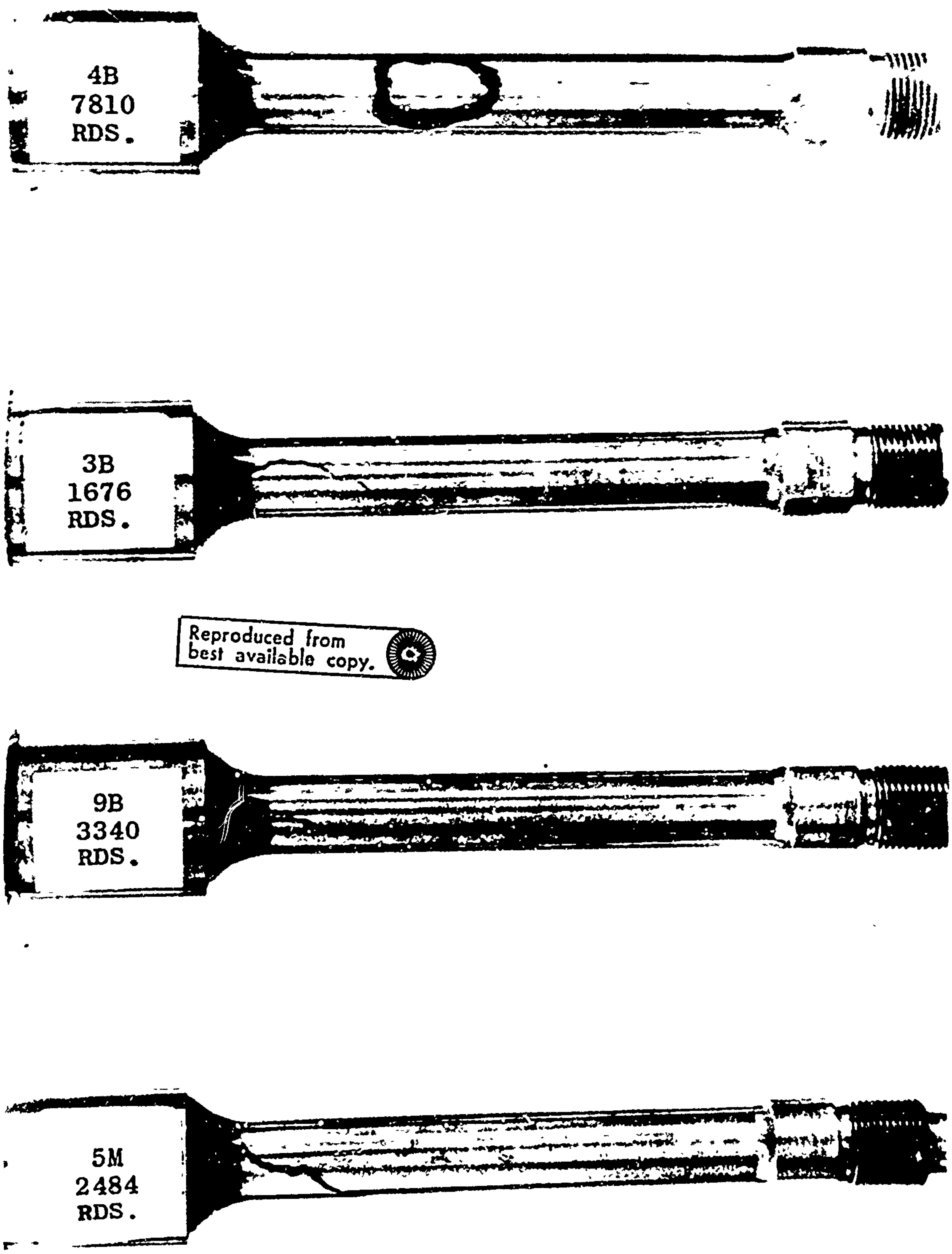
NO.	PAGE
1. Field Failure Photos	65
2. Tube Section and Specimen Location	66
3. Failed Specimens	67
4. Mechanical Properties of Forging	68

M




SPECIMENS
TAKEN FROM
THIS SECTION
12 O'CLOCK
KEYWAY
1 3 5 7 9
2 4 6 8
10

M



MECHANICAL PROPERTIES OF FORGING

TEST BAR	YIELD STRENGTH (PSI)	TENSILE STRENGTH (PSI)	ELONGATION (%)	REDUCTION IN AREA (%)	CHARPY (FT.LBS)
B	188,000	202,500	9.6	21.3	12.5
B	189,000	203,500	8.4	11.5	---
M	179,000	198,000	9.8	21.3	13.5
M	185,000	200,500	8.0	14.8	---

M

N

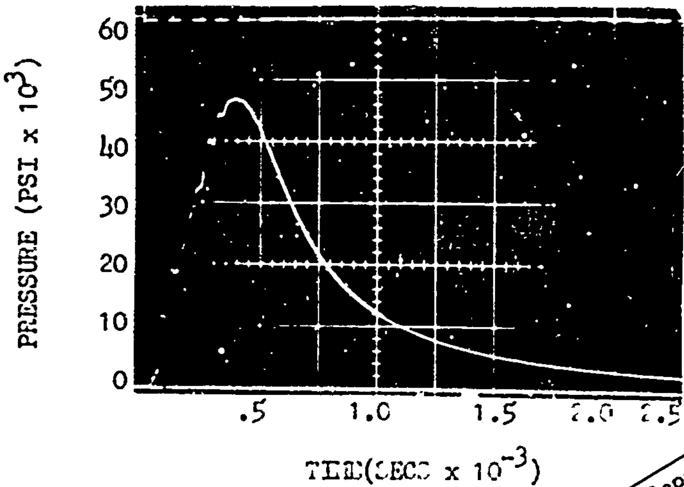
APPENDIX N

7.62MM AMMUNITION CALIBRATION

NO.		PAGE
1.	Ammunition Calibration	69

N

AMMUNITION CALIBRATION



TYPICAL P-T CURVE

7.62MM (M14 Rifle Mat'l) Test   Ammo Lot WRA-22731

Calibration	Date	Mean Pressure	Std Dev.	Mean Velocity	Std Dev.
Original	8/67	44,300	1000	Not Avail.	Not Avail.
1st Check	11/70	47,800	1300	2701	16
2nd Check	2/71	47,900	1100	2740	28

7.62MM (M13E1 Cannon Mat'l) Test   Ammo Lot WRA 22896

Calibration	Date	Mean Pressure	Std Dev.	Mean Velocity	Std Dev.
Original	10/68	45,300	1000	2751	19.7
1st Check	11/70	47,500	1600	2687	28
2nd Check	2/71	48,300	1200	2731	19

NOTE: Check tests were performed by Frankford Arsenal.
Hydraulic cycling pressure was established on original ammunition contractor calibrations.

APPENDIX O

MISCELLANEOUS REFERENCES

NO.		PAGE
1.	Miscellaneous References	71

0

MISCELLANEOUS REFERENCES

1. "Establishment of Cannon Life Criteria" -R. E. Weigle 1967 Watervliet Arsenal (Plus additional R&E laboratory test data).

2. "Fatigue Characteristics of Open-End Thick-Walled Cylinder Under Cyclic Internal Pressure"; T. E. Davidson, R. Eisenstadt, A. N. Reiner - 1962 Watervliet Arsenal WVT-R1-6216.

3. "175MM M113A1 Gun Tube Special Test for Service Life"; B. B. Brown, T. E. Davidson, D. G. Forkas, M. E. Kraut, T. Moraczewski, A. N. Reiner, P.K. Rummel, R. Soanes Jr. - 1971 Watervliet Arsenal.